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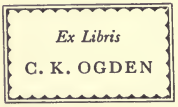

MAN AS A GEOLOGICAL AGENT

STORETON QUARRY, CHESHIRE.
(Geological survey photograph.)

MAN AS A GEOLOGICAL AGENT

AN ACCOUNT OF HIS ACTION ON INANIMATE NATURE

BY

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WITH A FOREWORD BY

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TO
THE MEMORY OF MY MOTHER
MARY SHERLOCK

FOREWORD

MANY animals alter the surface of the earth to a certain extent to suit their own convenience and comfort. Some burrow or dig holes, others make mounds of various kinds; while some, such as the beavers, dam and alter watercourses, with results that are by no means insignificant. The turbaries or peaty swamps of the Lea valley in Essex, for example, are probably due in great part to the work of the beavers which lived there in prehistoric times. The activities of animals in altering their surroundings, however, are not progressive. Animals merely repeat the same old instinctive course, and the world from their point of view never becomes a more desirable place to live in.

Man, on the other hand, ever since his appearance, has progressed in adapting surrounding nature to his needs. Commencing by picking up any broken piece of stone useful for his purpose as an implement, he would gradually begin to chip the stones himself to make them of the required shape. Next, he learned the preparation of metals which would provide tools both more efficient and more varied. Finally, his materials for industry became almost unlimited. Beginning with the roughest of shelters in the forest, he would soon learn to appreciate the greater comfort

of an overhanging rock or a cave. The success of a pile of stones heaped up outside to increase protection from the blast, would lead to the building of independent structures away from the rock-shelters. These primitive houses would be grouped for safety within an enclosure. In time, indeed, the village or town would arise, and modern conditions would gradually be reached. Beginning by digging holes in the ground to obtain materials for his tools and to make traps for catching large animals for food, he would gradually learn the advantage of shaping the surface to his convenience. In short, one successful undertaking would lead to another, and there could never be an end to his enterprise.

As soon as man became grouped in definite communities, new problems would arise, and his interference with surrounding nature would extend in fresh directions. We have learned some of these directions from the remains of the early civilisations of the East. There would be the supply of building material and road metal, the provision of water, the removal of waste, and especially the making of lines of communication with neighbouring settlements. In all these directions there has been continual progress as civilisation has advanced, and in a long-settled country it is now sometimes difficult to realise the primitive conditions under which the various developments began.

Dr Sherlock could not have chosen a more appropriate long-settled country than Great Britain by which to illustrate the extent of man's activities in altering

the earth's surface to suit his needs. London is an excellent instance of a big city in which the accumulations and works of centuries have converted an irregular and varied wilderness into a convenient and comfortable habitation. The story of the tracks, roads, canals, and railways of the country is exactly that of the progressive changes in transportation in general. The disturbances produced in surface contours and in watercourses by the making of reservoirs and filters are equally typical of man's activities in providing water for large communities. The problems of harbours and dockyards are also much the same in Great Britain as elsewhere. There may be differences of opinion as to the adequacy of all the data on which Dr Sherlock estimates the amount of the changes in terms of weight and bulk; but several of his calculations are both novel and instructive.

Many of the questions discussed are of more than academic interest, and are of great practical importance in everyday life. Alterations in the lower reaches of a stream, for example, may modify the erosive power of certain sections of its upper course; and a change in the deposition of its sediments may have unexpected results. Harbour works and protective structures on one part of a coast may have disastrous effects on another part, and even with our present experience it is not always possible to predict what these effects will be.

Most interesting of all, perhaps, is the question whether man, by his prodigious combustion of coal and other carbonaceous substances, is producing more

carbonic acid than can be eliminated by ordinary natural processes. If this production is excessive, the result eventually may be an unwelcome change in his atmospheric surroundings. Man has, indeed, learned to be cautious in altering the balance of nature in the world of plant and animal life. He may be approaching a stage when he should pause to consider whether his use and alteration of the crust of the earth itself are for future as well as for present advantage.

ARTHUR SMITH WOODWARD.

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MAN AS A GEOLOGICAL AGENT

CHAPTER I

INTRODUCTION

MAN'S action on Nature has two aspects: a geological and a biological one. The two are intimately connected. The biological effects of Man's activities include such matters as the destruction of species of animals and plants, a work that can never be undone; for we have reason to suppose that the conditions that produced a particular species, by evolution, will never recur exactly, and so a species once destroyed will never be reproduced. Man has also created new species and varieties of animals and plants, e.g., the many kinds of dogs, sheep, cattle, pigeons, fowls, and conservatory and garden plants. There is reason to suppose that without Man none of these would ever have existed. Moreover, the numbers, relative and absolute, of species of living beings have been greatly modified by him: where Nature intended a forest, Man grows corn and potatoes. Plants are enabled by his aid to grow in places naturally unsuitable for them; others, e.g., weeds, are driven out of places for which they are naturally fitted. The destruction of birds encourages insect-life until it becomes such a pest that Man has a struggle to curb it. Even in the world of microscopic creatures the effect is seen, and Man's influence is felt by bacteria and protozoa as much as

by the largest living beings. In this book the geological aspect alone is considered: the biological aspect is worthy of a separate investigation.

Man's geological activities are primarily as an agent of Denudation; in which capacity he is probably more effective, in a thickly populated country, than even the sea itself. In addition, in mining operations he disturbs the flow of underground water, and causes subsidences. Among the mineral substances he produces are compounds unknown to Nature. Man disturbs the courses of rivers; fills lakes and makes new ones; checks or promotes sea-erosion; and modifies climates.

Some of these effects are geographical as well as geological in their nature, but the difference between Physical Geography and Geology is not easy to define. Indeed, some geographers, among them Professor G. G. Chisholm, admit that there is no real dividing line between the two. This school of geographers consider that it is convenient to restrict their subject to Anthropogeography, or the study of the effect on Man of local characteristics of the earth's surface, though some members of the school, such as Professors Davis and Penck, would include the effect of local characteristics on all living organisms. Much has been written about this aspect of the matter, but strangely enough the converse, i.e., the effect of Man on local characteristics, seems to have attracted scarcely any attention. There are accounts by Brunhes, Woeikof, Marsh, and others, of the results of irrigation, the cutting down of forests, tillage, etc., on the welfare of the human race, but I have been unable to discover any comprehensive account of the effect of Man on geographical or geological conditions.

The subject is one that may appeal not only to geologists and geographers, but to all thinking people, for it is essentially philosophical. An attempt is made here to treat it in a scientific and at the same time

a popular manner. To present the results in an essentially popular manner might be interesting without being valuable; a purely scientific treatment would appeal only to the few.

Much of the work is compilation, and data have been collected from all sources. Some new information, however, has been obtained by direct investigation; and the aim throughout has been to give the data for all statements. It has been difficult to avoid the weariness and obscurity produced by the setting out of too many figures, and, on the other hand, to give sufficient data to justify the conclusions.

Geology has suffered under the aspersion of being an inexact science, for as a rule its conclusions do not admit of the mathematical accuracy so highly esteemed by the physicist. However, the dictum that we cannot be said to know anything until we have measured it, applies to geology as much as to physics, and we should aim at obtaining as near an approximation to the true figures as circumstances permit. Many of the estimates of quantities here given have probably not been attempted before, as, for instance, the total amount of rock mined and quarried in Great Britain, or the quantity of road-paving materials ground to powder by traffic; and such estimates are not supposed to be more than rough approximations to the truth. If investigators are led to criticise and strive to produce better estimates these first approximations will have served a useful purpose.

The apparently erratic manner in which Man interferes with Nature makes it particularly difficult to estimate the net result of his activities. The evidence given on page 151 as to subsidence at Ashton's Flash, Northwich, offers a typical illustration of the complexity of human interference with Nature, and the difficulty of measuring it. We have in this case to consider: (1) subsidence due to pumping of brine; (2) excavation of sandstone at Liverpool; (3)

dredging in the Weaver; (4) the introduction of coal-ashes, i.e., the waste product of coal mined in Lancashire; (5) the partial filling of the subsided area at Northwich by the materials obtained in (2), (3), and (4); (6) subsidence in Lancashire caused by mining the coal sent to Northwich. The only way of understanding fully the extent and character of Man's interference with Nature is to measure the factors involved in any individual instance, such as the illustration given.

Man's great engineering feats are so widespread that it would be a herculean task to sum up their total effect on Nature. It is wise, therefore, to limit the investigation to a definite area, such as Great Britain, which provides a reasonable chance of obtaining the necessary data. Even in this case it is very difficult to estimate quantities. This arises in part from the incessant changes in the form of published statistics and papers. Thus if we take the annual reports on Mines and Quarries, issued by the Home Office, we notice new groupings every few years, so that it is impossible to distinguish any item for many years.

It is only since 1895 that the outputs from mines and from quarries have been separated, and all quarries less than 20 feet deep are still ignored entirely, although their total output may be equal to that from the deeper quarries. Not uncommonly counties which have been grouped together for a few years are re-grouped, with the result that the output of any one district cannot be accurately known. One reason for this is the objection of many firms to allow information to be published which might be interesting to a rival, and so groupings of figures are deliberately arranged to disguise, instead of to disclose facts. A similar explanation probably accounts for the fact that engineering papers rarely give the total quantities of materials used and rock, etc., excavated; generally these facts are suppressed.

Still further difficulties arise when quoting statistics. Thus, at one time a ton of copper contained 21 cwts.; also for many years a ton of rock-salt, but not of salt made from brine, contained 26 cwts., and the change to the normal ton was made in 1896 without notification in the statistics. Such traps for the unwary prevent us from adding together the annual outputs for these minerals until corrections have been made.

In the following chapters there is no mention of the effects of the Great War. This is partly because scarcely any data are available by which the geological effects could be measured, and partly because the destroyed lands were fortunately outside the area specially dealt with. That the excavation of soil and rock, and the destruction of buildings, by mines and shafts, was very great is well known. We are told that in France alone 319,269 houses were totally and 313,675 partially destroyed, in addition to nearly 5,000 bridges, 52,000 kilometres of roads, 8,000 kilometres of railway, and nearly 21,000 factories. The *débris* produced is of the type described in the chapter on London (p. 161), but was formed rapidly instead of being the slow accumulation of centuries. The amount of rock excavated on the Western Front for road-metal during six months of 1917 alone was one and a half million tons.

An important question that needs consideration is the effect of Man's geological activities on the estimates of geological time, since, if his activities are ignored, the present rate of denudation, on which estimates of the time-scale are usually based, will be quite misleading. Another even more interesting question is to what extent, if at all, Man's activities are in opposition to natural forces, and this is discussed in the concluding chapter.

Among the publications consulted for this work are the Proceedings of the Institute of Civil Engineers,

comprising more than two hundred volumes; Reports of Royal Commissions on Water Supply, Canals, Coast Erosion, Sewage, and Coal Supply; the Mineral Statistics issued annually by the Home Office; the Census of Production issued by the Board of Trade; the volumes of "The Quarry," "British Clayworker," "Water;" and numerous works of a miscellaneous character mentioned in the Bibliography. Previous works dealing with the subject are few, the most important being "The Earth as Modified by Human Action," by G. P. Marsh; the third and last edition being published in 1877. This book contains a great mass of information, but the greater part of it is devoted to the question of the effects of the destruction of forests, and the geological aspect of Man's work is but briefly considered. The treatment, too, is scarcely scientific; for example, the author states that the making of the Panama Canal is impossible. Nevertheless the book is most important, and apparently the only one on the subject in the English language. Sir C. Lucas, in his Presidential Address to the Geographical Section of the British Association in 1914, indicated the chief lines on which Man acts as a geographical agent; and Mr H. M. Cadell has given an account of Man's work in transforming the Firth of Forth. In his "Text-Book of Geology," fourth edition, 1903, Sir A. Geikie devotes three pages to a brief outline of the subject, and points to it as an important branch of geology worthy of investigation in the future. T. C. Chamberlin and R. D. Salisbury in their large text-book "Geology," devote less than two pages to "Man as a Geological Agency," and almost the whole of this brief notice refers to Man's biological, rather than his geological activities.

The most important geological result of Man's activities is undoubtedly the effect on denudation, and this question is therefore dealt with in Chapters II and III, under the two sections Excavation and Attrition.

Subsidence of the earth's surface naturally follows the excavation of minerals, and is described in Chapter IV. Next follows an account of Man as a rock-maker, his accumulations being for the most part waste products. It is in cities and towns that accumulation preponderates over denudation, and in Chapter V a somewhat full account is given of the growth of London, considered as the type city, while in Chapter VI Accumulation in general is described. Alterations along the coast are partly destructive and partly constructive, and are all grouped together in Chapter VII. The Circulation of Water in its various forms, both above and below the surface of the earth, is one of the most important factors in geology, and the modifications caused by Man are described in Chapter VIII. Changes in Climate and Scenery form the subject of Chapter IX, while in Chapter X the meaning of the facts described in the preceding chapters is discussed. A list of books and papers used in the preparation of the work is given as an Appendix. It seemed desirable to give full references for all the statements made, but this involves numerous foot-notes, which appear to be a source of irritation to many readers. It is believed that it is a sufficient indication of the source of the information to mention the author's name, if only one work by him appears in the list, or a brief title if there is more than one work by him listed.

It is perhaps worth recording that the idea of the present work was suggested by a passage in Huxley's "Evolution and Ethics," which seemed to point to an apparent interference with Nature by Man. But before interference with Nature can be assumed to be more than trivial it is necessary to discover what Man actually does effect, and it is this question that forms the subject of the present work.

During the course of the compilation of this volume I have received information and advice from many friends, and where data so obtained have been

used the source is acknowledged. In some cases, however, information could not be used; thus I am indebted to Messrs The Hodbarrow Iron Co. for permission to use their detailed sections showing the progress of subsidence of the Inner Barrier at Hodbarrow concurrently with mining operations. The sections, however, would have needed large folding plates, and so, with regret, they have been omitted.

I am under a special obligation to Dr A. S. Woodward, who has kindly contributed a Foreword. To Mr G. W. Malcolm, Messrs Bolckow, Vaughan and Co., Mr Ll. Treacher, and the Geological Survey, I am indebted for illustrations. Mr H. W. Greenwood has helped me with photographs, and Major F. Sadler has given me valuable data. Mr C. V. Crook, Librarian at the Museum of Practical Geology, and Mr C. P. Chatwin, formerly Librarian to the Geological Society, have given me much assistance when searching the literature of the subject. Finally I am indebted to Mr T. C. Cantrill for expending much time and trouble in reading and criticising the MS.

CHAPTER II

DENUDATION: EXCAVATION

THE characteristic of marine denudation is the removal of the land in vertical slices down to the level at which wave-action ceases, and the result is the formation of a shelf round the coast. The main characteristic of sub-aerial denudation is that the land is pared away horizontally, so that the ultimate result is the formation of a plain, apparently horizontal, but really rising inland from the coast so gradually that water will just flow over it to the sea. Such a plain is known as a peneplain.

Human denudation acts differently from both of these. In quarrying road-metal and building-stones the hardest rock, the bony framework of the land as it were, is removed in preference to the soft clays and sands picked out by natural agents. Where Nature would leave a hill of hard rock, there Man leaves a hole. At other times it is soft rocks that Man removes; hence a characteristic difference between human and natural denudation is the apparent lack of plan in the former. Again, human denudation is localised: instead of a slice being planed off some considerable area and rounded contours left, Man digs here and there and leaves the surface of the land broken and angular. At the margin of the land he often enhances the separation of land and water by

dredging or embanking the shallow places: a swamp may be turned into dry land, or, on the other hand, a low-tide mud-flat is removed by dredging, and its site becomes permanently submerged.

A characteristic of human denudation almost unique is the removal of rock from below the surface of the land while leaving the surface itself undisturbed except by subsequent subsidence. The only cases in nature where anything of the kind occurs are the removal of lava and volcanic ash, and the formation of subterranean passages and caverns by the flow of underground rivers in limestone regions.

The greatest single feat of denudation ever performed by Man is probably the digging of the Panama Canal, where 200,000,000 cubic yards, largely of hard rocks, have been removed; but the greatest aggregate effect of human denudation is to be found in the countries most densely populated and most highly civilised, such as Western Europe and the United States of America. Here, too, we have the fullest information relating to the changes effected by Man. The United States have perhaps the most complete data, but the country has been much more recently settled than Great Britain, and is, moreover, so large, and has still such extensive areas sparsely inhabited, that it seems best to take Great Britain for detailed study.

Under Excavation we have to consider: (1), the materials removed from quarries, mines, and excavations of all kinds, and (2), the quantities dredged in rivers and estuaries.

For mines and quarries the annual volume issued by the Home Office, entitled "Mines and Quarries. General Report and Statistics," is the most important source of information, although imperfect in many ways. For example, quarries less than 20 feet deep are ignored, and yet these are very numerous, and collectively produce certainly half, and probably more

than half, of the gravel, sand, and clay excavated. For coal we also have the Reports of the Royal Commissions on Coal Supplies, and there are numerous other sources of information (see Bibliography, p. 348).

From the earliest times a certain amount of excavating must have been done by Man, but with the increase of civilisation and population and the growth of industry the quantity has increased by leaps and bounds, so that the amount of denudation before the eighteenth century is very small as compared with that effected since—a fortunate circumstance for our purpose, as it is only within comparatively recent years that we have figures by which it can be measured.

Coal.—It is believed that coal was used in small quantities by the Romans, as fragments have been found in the ruins of Uriconium and other places. Before the twelfth century statements about the use of coal are exceedingly fragmentary. After that period there is a fair amount of information about the coal trade from the Tyne and the Wear, but very little about other parts. In 1234 Henry III. confirmed a Charter, by John, to Newcastle, giving a licence to dig coals and stones. In 1306 the burning of coal was prohibited in London, although the prohibition was not effective. In the reign of Henry VIII. there was a considerable trade with France from the Tyne. In 1638 the export from Newcastle was not less than 200,000 chaldrons (530,000 tons). Coming to more recent times, the output of coal for 1819 was estimated by R. C. Taylor at 13 million tons, and for 1848 at 31½ million tons. The Coal Commission estimated the output in 1854 at 64,661,401 tons, and by 1865 it had grown to 98,150,587 tons. The output has grown with increasing rapidity, and in 1913 had risen to 145,535,669 tons.

The Coal Commission estimated the output from 1500 to 1850 at 2,850 million tons. The output

from 1850 to 1870 was 1,620 million tons. Home Office returns give the output from 1873 to 1913 as 7,940,578,615 tons. For 1871-2 we may estimate the output at the same rate as for 1873, i.e., 126½ million tons per annum. Adding together, the total output for Great Britain from 1500 to 1913 is, therefore, 12,667 million tons. Compared with these figures any coal got before 1500 is negligible.

In early days a great deal of small coal was consumed upon the colliery waste-heaps, and this is not included in the above estimate. Mr Atkinson estimated the waste in his district of Durham, south of the Wear, at 2,404,215 tons in 1860, and Mr Dunn estimated the waste from the rest of Durham, Cumberland, and Northumberland, during the same year, at 834,117 tons. Jevons conjectured that the waste was at least 5 million tons in all. Existing coal-tips contain between 15 and 30% of coal, the former figure being a low average one.

At first coal was dug at the surface wherever it cropped out, but this coal was soon nearly exhausted, although even at the present day a little is occasionally got in this way, as, e.g., during coal-strikes.

In the case of the mining of coal, denudation takes the form of the removal of thin inclined sheets of rock, from the surface to a depth of 2,000 to 4,000 feet, and there is no natural agent that acts in anything like this manner.

The average weight of a cubic yard of coal is from 2,103 to 2,243 lbs., so that for practical purposes a cubic yard weighs a ton. As workable coal-seams range in thickness from 30 feet to as little as 1 foot, it is frequently necessary, when the seam is thin, to remove much of the overlying and underlying strata. Moreover, the sinking of the shafts means the excavation of additional large masses of stone. The bulk of the materials removed in these ways is probably equal to half that of the coal.

Up to the end of the eighteenth century it was not usual to extract more than two-fifths of the coal when working at a greater depth than 100 fathoms. At present, allowing for the thick barriers round the margin of the property, about $77\frac{1}{2}\%$ is removed.

One result of the removal of a coal-seam is subsidence of the surface. To some extent this is counterbalanced by the packing of the workings with the rock that has to be removed when the seam is too thin for the excavations to be entirely in the coal, or because the roof was " tender." The loose fragments of rock, however, although they occupy much more bulk than the solid rock from which they were made, do not entirely compensate for the loss of the coal, and, moreover, they crush together under the enormous pressure of the superincumbent strata. The pillars of coal frequently left to support the roof, do so only temporarily, and after the removal of such timber as can be got away, they crumble under the weight of the roof. In addition, the floor of the workings frequently rises up in a ridge, owing to the weight of the strata above being transmitted through the pillars to the floor, and in the end roof and floor meet. After this has happened we have a belt of smashed and pulverised strata descending along the line of the coal-seam from the surface to the lowest depth at which the coal has been worked. The shallower part of the seam will probably have been worked some considerable time before, and the modern deeper workings carry on this " shatter-belt," as it may be called, to greater depths. The shatter-belt may be broken up into separate blocks by the wide barriers of coal left round a property boundary, and by the areas of coal still unworked. The thickness of the shatter-belt will depend to a great extent upon the depth below the surface, increasing with depth.

A shatter-belt resembles to some extent fault-stuff,

i.e., the broken material between the two faces of a fault, and both may be pervious to water. As a rule faults have a high and shatter-belts a low inclination from the horizontal. The two faces of a fault have been shifted relatively to one another; in the case of the shatter-belt there is no such shift. Another important difference is that the shatter-belt has a relatively small extent, and ends abruptly at the boundary of a property, or may be cut off by a pillar of unworked coal. These limitations prevent the free circulation of water through the porous mass, and instead of forming subterranean rivers they form reservoirs of stagnant water that act chemically on the saturated rocks.

Metalliferous Mining.—Metalliferous mining in Britain is of great antiquity. Robert Hunt thought that it was 3,000 years old in this country, and that the bronze used by primitive man must have been obtained from the Indian Archipelago, from Spain, or from Britain. According to Julius Cæsar, although brass money and iron rings were in use in Britain in his day, the brass was all imported.

In the north of England there are many evidences of ancient mining. In Allendale and on Alston Moor, large masses of scoriæ—no doubt Roman—have been found. At Greenhow Hill, near Pateley Bridge, there are remarkable examples. In Derbyshire, waste heaps containing galena are found in all parts, the galena in most cases having been converted into carbonate of lead. Modern smelters have for a long time obtained lead from slimes and slags left by the Romans. In Shropshire, and particularly in the Shelve district, there are remarkable examples of Roman mining. Thos. Wright says that in this district two or three veins cropped out almost parallel to one another. The Romans began at the bottom and worked them upwards, filling the old hole with new waste. In the upper parts vast cavernous places have been left. In

the Forest of Dean they sank a pit from 20 to 30 feet in diameter, and at the bottom found a vein of ore and followed it. In the Brendon Hills some of their iron-mines are said to extend from 200 to 300 feet underground.

The quantity of ores worked by the Britons and Romans during five hundred years must, says Hunt, have been enormous. In the Mendip Hills some of the caves are in part of artificial origin. At the Waldegrave Mines, and at Charterhouse, immense deposits of slimes and slags containing from 20 to 25% of lead show that the Romans must have extracted from two-thirds to three-quarters of the metal. Some authorities consider that Wookey Hole and other caves are due to Roman excavations. Although the slags have probably been re-worked for a considerable period, yet in ten years, 1871-80, about 9,000 tons of lead were extracted from slags, though some of these may not be older than the sixteenth century. The Romans also mined copper, and some of the most perfect remains of their work are to be seen at Abergele, in Denbighshire.

In the border counties of England and Wales, quantities of iron slag and cinders are found. In the Forest of Dean in Monmouthshire, there are immense beds of iron-slag that still contain at least half of the metal. Cinder Hill, Western Herefordshire, the site of a Roman bloomery, is marked by an immense mass of scoriæ. Iron was mined by the Romans in the Mendip Hills, Derbyshire, Yorkshire, Cheshire, Co. Durham, Northumberland, Cumberland and Lincolnshire.

In 1844 a Mr Turner found in Maresfield Parish, Sussex, a heap of scoriæ with Roman pottery, covered by a foot of earth. The heap was originally from 6 to 7 acres in extent and from 2 to 12 feet deep. The materials had been much employed for the repair of turnpike roads. The scoriæ are richer in iron than

other " cinders " of the neighbourhood, and are therefore more valuable for road-making. The chief Roman iron works were situated in the Forest of Dean, where scoriæ were so abundant that in the sixteenth and following centuries iron-masters used them for their principal supply of ore. The Romans are believed (Meade) to have left the vast heaps of iron scoriæ to be seen on the moors near Lanchester and Chester-le-Street, Co. Durham, and elsewhere.

H. B. Woodward, writing in 1876, recorded that at Stoke Hill, in the Mendips, an old refuse heap, from the lead-workings, measured about a mile long, 200 to 300 yards wide, and from 12 to 20 feet deep. It was estimated to contain 500,000 cubic yards of materials. The slags, which contained on the average 20% of lead and the slimes 5%, were being re-worked.

Some of the lead-mines of Derbyshire are believed to have been worked by the Saxons. Domesday Book mentions that at Wirksworth there were three, besides others at Bakewell, Ashford, Crich, and Metesfoed.

Blasting was first introduced into England by Prince Rupert, who employed German miners, probably between 1636 and 1645, to work the copper-mines at Ecton, Derbyshire. Previously the only way of getting the ore was by making a fire against the working-face in the evening. By morning the vein-stuff was so loosened that it could be picked or wedged down. Many old hillocks in Derbyshire contain great quantities of cinders, of either slag or coal. " Hillocking," or the turning over of the old hillocks for ore, was introduced in 1720 by Welsh and Cornish miners, and several great levels were made at the same period to unwater mines at Wirksworth, Youlgreave and Castleton.

World's Output of Metalliferous Ores.—Before dealing with the British output we may turn to other

countries for a brief summary. In a recent work entitled " The Deposits of the Useful Minerals and Rocks," F. Berschlag, J. H. K. Vogt and P. Krusch give estimates of the total world's output of several common metals. Details of the calculations are not given, and the degree of accuracy to be ascribed to the results is unknown, but the book seems carefully prepared. For the world's output of pig-iron the following figures are given:

	Million tons		Million tons
1911 . .	63.25	1831-1840 .	some 24
1901-1910 . .	528	1821-1830	,, 15
1891-1900 . .	317	1811-1820 .	,, 12
1881-1890 . .	223	1801-1810 .	,, 10
1871-1880 . .	148	1701-1800	perhaps 50
1861-1870 . .	99	1601-1700 .	,, 40
1851-1860 . .	65	1501-1600 .	,, 30
1841-1850 . .	36		

During 1801-1911 some 1,540 million tons of pig-iron were produced. Including the output of earlier centuries, so far as relates to ore *in situ*, i.e., leaving out of account the lake- and bog-ores, half of the total has been produced in the last twenty-five years, and the production from the earliest times is about 1,700 million tons. The authors reckon the average yield of pig-iron since 1890 to have been 45% of the ore, from 1860 to 1890 about 40%, and still earlier only 35%; hence the pig-iron made since the earliest times represents something more than 4,000 million tons of ore. Taking into account that in 1910 a million tons of pig-iron were produced from roasted pyrites, old slags, etc., the average iron content of ore produced in that year may be reckoned at 45%. The ores of Great Britain, Germany and France are assumed to yield on the average one-third their weight of pig-iron. To-day more pig-iron is produced in a year than formerly in a century.

The same authors give the world's output of metallic copper as follows:

			metric tons
1901-1910	output		6,945,000
1891-1900	,,		3,770,000
1881-1890	,,		2,252,000
1871-1880	,,		1,050,000
1861-1870	,,		760,000
1851-1860	,,		510,000
1801-1850	output	about	1,400,000
1701-1800	,,	,,	1,300,000
1601-1700	,,	,,	750,000
Still earlier	,,	,,	2,000,000
Total output		,,	21,750,000

Of this quantity Great Britain produced about 1,100,000 metric tons (=1,080,000 tons). The estimate obtained by combining the figures given by Hunt and by the Home Office was 928,500 tons of copper up to 1913. While the difference between the two estimates is considerable, they are of the same order of magnitude and we may regard the total output of copper from Great Britain since the earliest times as somewhere about a million tons of the metal.

The figures given by Berschlag, Vogt and Krusch for the world's production of other metals, since the earliest times, are:

	Tons
Nickel, first produced in 1825, total to 1910 about	200,000
Gold.—Before 1875 and in greater part since 1493 =	9,453
1876-1900 =	5,582
1901-1909 =	5,000
1910 =	701
Total production of gold to 1910 =	20,737

The figures for silver are:

Before 1875 and in greater part after 1493	=	180,511 tons
1876-1900	=	98,325 ,,
1901-1909	=	49,191 ,,
Total production of silver to 1909	=	328,533 tons

Let us now return to the British output and consider it a little more closely.

Tin.—It is common knowledge that tin has been mined in England since the days of the Phœnicians. Hunt thought it possible that the original stanniferous deposits of ancient Britain are now submerged, and he pointed out that a survey of Edward IV. gives twice as many acres to Cornwall as it now contains.

In addition to stream-tin the metal was obtained from veins. Hunt states that in the parish of Kea, Cornwall, a tin lode had been followed until the miners were stopped by water. Later on an adit was made to drain the lode, probably by the Romans.

After the Roman occupation there is no evidence of mining for a long period. Throughout the Middle Ages European nations must have drawn tin supplies from this country. A considerable demand would be caused by the introduction of bells in churches in the sixth and seventh centuries. Bronze cannon were introduced in the thirteenth century, and pewter (tin and lead alloyed) in the fifteenth century. The Cornish tin-mines were held by Jews until Edward I. expelled them from England. In 1240 Cornwall is said to have supplied all Europe with tin. In Queen Anne's reign, five years' consumption amounted to 5,000 tons. Up to 1713 the black tin (oxide of tin, cassiterite) produced was not over 1,600 tons per annum, but by 1748 it had risen to 2,329 tons and nine years later was 2,595 tons.

Carew, writing in 1769, says that the miners

followed the "lead" downward sometimes for 40 or 50 fathoms. He says that it was their practice to sink shafts and make passages until the air began to fail, when they made a new shaft. Adits were driven for draining the mines. Gunpowder began to be employed in 1689, but even in 1733 its use was uncommon.

Hunt gives the following figures. For the hundred and ten years ending 1715 the annual production of metallic tin was about 1,500 tons. During the next thirty years a gradual increase took place. In 1742 a committee stated that the tin raised annually in Cornwall had averaged, for many years past, about 2,100 tons. Hunt's final estimate of the amount of tin (metallic) got in England is:

In 500 years B.C.	50,000 tons
In the 500 years of Roman occupation	50,000 ,,
To 1066, landing of William I.	100,000 ,,
To 1300, Edward I.	369,800 ,,
To 1500, Henry VII.	42,048 ,, ?[1]
To 1600, Elizabeth	680,100 ,, ?
To 1636, Charles I.	30,000 ,, ?
To 1740, Computation of Mines Royal	235,000 ,,
To 1834, William IV.	202,000 ,,
To 1860, Victoria	162,000 ,,
To 1880, Victoria	195,223 ,,
Total	3,016,171 tons

The proportion of metallic tin in dressed ore being 1 in 1·58 (Home Office Statistics), the total dressed tin ore obtained in England from the earliest times to 1880 is, on Hunt's estimate, 4,765,500 tons. From 1880 to 1913 the output (Home Office Statistics) was 342,369 tons, giving a total output from England, of dressed ore, from the earliest times to 1913, of

[1] The figures queried appear to be of doubtful accuracy as they seem to be inconsistent with the others.

5,107,919 tons (say 5,100,000) containing 3,233,493 tons of metal (say 3,233,000).

J. H. Collins, whose knowledge of Cornish mines was unrivalled, also estimated, in 1912, the quantity of tin raised in Cornwall and Devon since the earliest times. He also gave a description, from which the following notes are taken, of some of the large excavations for tin and china-clay.

Carclaze.—An openwork two miles north-east of St Austell. Originally worked for tin only but now exclusively for china-clay. Locally, the pit is said to have been worked since the time of Henry VII. In 1829 the pit already covered more than two acres, and was 126 feet deep. At that time the clay was regarded merely as refuse, to be washed out through the adit as speedily as possible. The latest survey is by Mr R. Symons (1877), who found the area of the pit to be 13 acres, and the greatest depth 132 feet. Symons stated that the greatest length of workings, including the eastern part known as Little Carclaze, is nearly half a mile. The total quantity of tin-bearing ground removed must therefore amount to at least one million tons, besides several million tons of non-stanniferous clay ground. Collins remarked in 1892 that the area of the top of the pit must be at least 18 acres, the old bottoms being largely filled up with debris from the new pit opened to westward.

Rock Hill.—The main excavation is nearly circular, and not much less than 150 feet in diameter and 40 feet deep. Opening out of this on the east side is another pit, about 100 feet long, 30 wide and 20 deep. Tin veins and their branches traverse the pit in every direction. Between 1872 and 1874 the average yield of tin was 7 lbs. per ton broken, and this proved unremunerative. Carclaze and Rock Hill are examples of stockworks in granite. The aggregate volume of the granite stockworks unconnected with lodes must be at least 250,000 cubic fathoms, or over

four million tons, averaging about 8 lbs. of tin to the ton, or, say, 14,000 tons of black tin in all already extracted.

Collins next described the tin stockworks in granite associated with workable lodes. One of these is *Balleswidden*. The ground removed here was roughly 600 yards long, 8 wide and 80 deep. Allowing for pillars, this did not exceed 55,000 tons, which would give 50 lbs. of tin to the ton in order to account for the 12,000 lbs. of tin sold. *Ding Dong*, *Beam*, *The Bunny* and *Birch Tor* are of the same class. Collins estimated that for this class of stockwork not less than two million tons of rock have been excavated, yielding about 40,000 to 50,000 tons of tin.

Tin stockworks in elvans comprise *Wherry Mine*, *Wheal Jennings*, *Belowda Hill*, *Wheal Vor* and others. The quantity of elvan removed is estimated at a million tons with an average yield of a little under $\frac{1}{2}\%$ of tin, say, 4,500 tons.

Tin stockworks in killas were probably worked in very ancient times. They include *Wheal Prosper* and *Michell*, half a mile westward from Lanivet Church. The pit is 800 yards long, 30 wide at the bottom, and averages 90 feet deep. *Mulberry*, in line with and west of *Wheal Prosper*, is one of the most ancient open workings in Cornwall. At the bottom the excavation is about 400 yards long, 30 wide, and averages 80 to 100 feet in depth. *Great Wheal Fortune*, partly open and partly mined, has been worked for generations. Not less than 200,000 tons of ore containing, say, 9 lbs. of tin to the ton have been extracted. From the whole of the tin stockworks in killas it is estimated that 375,000 cubic fathoms, say, 6,000,000 tons, have been removed, and probably much more. The average yield of tin was 18 lbs. per ton where there was a definite lode, and 6 lbs. per ton where there was not. At least 250,000 tons of tin oxide must have been obtained.

The rock excavated in these various kinds of stock-works amount in all to 13 million tons, or about 6½ million cubic yards. Collins estimates roughly that the tin-bearing rock has a surface area of not quite half a square mile. The tin-bearing superficial deposits of Cornwall and Devon he thought would cover 340 square miles of an average thickness of 18 inches, which would amount to 523,192,000 cubic yards, or about 1,000 million tons containing, say, ¼% of tin oxide. Of this ground about four-sevenths have been turned over and had their tin extracted. This would mean the excavation and washing of nearly 300 million cubic yards of gravel and " head " (an accumulation of earth and stones found in non-glaciated districts).

Copper.—Up to 1845 the great bulk of copper-ores raised had come from Cornwall, and probably the whole of the Devon produce up to that date did not exceed 350,000 tons. Previous to 1800, Devon had not yielded more than about 1,000 tons of ore (" 10 tons of fine copper ") in any one year. In 1811 there were seven copper-mines in Devon producing together under 4,000 tons of ore. In 1845 Devon Great Consols was started; and in consequence Devon produced, from 1845 to 1890, at least 1,100,000 tons, or nearly 25% of the output of the West of England. J. H. Collins gives the output of dressed copper-ore from Cornwall and Devon as follows:

1501-1600	= 30,000 tons	1701-1800	= 1,700,500 tons
1601-1700	= 100,000 ,,	1801-1890	= 9,611,670 ,,
	Total to 1890	= 11,442,170 tons.	

Collins estimated that this mass of ore probably involved the raising to the surface, from an average depth of 600 feet, and subsequent treatment of at least 30 million tons of veinstuff, and nearly as much of absolute " deads "; that is to say the total mass raised would be about 70 million tons of mineral and rock.

Deep mining for copper probably began about 1700, although in 1678 mines sometimes exceeded 60 fathoms in depth. Deep mining was not possible until good pumping engines were installed, and Newcomen's patent was granted in 1705. This type of engine was used almost solely at first, but Watt improved it later. The discovery of copper at Parys Mt., Anglesey, in 1772, was a great blow to Cornwall.

Collins estimated the total length of the drifts and sinkings in the copper-mines of Cornwall and Devon, apart from all stoping, at 1,485 miles. The excavations would be on the average about 6 feet high and 4 feet wide.

Hunt has estimated the output of copper from Britain as follows:

	Tons
During Roman occupation, ore containing . .	5,000
To time of Edward I. (1341)	15,000
To reign of Elizabeth, and after introduction of German miners (say 1600)	47,000
To beginning of eighteenth century . . .	100,000
1770 to 1775. Copper ore raised 693,500 tons containing	37,500
1775 to 1800. Copper ore raised 1,450,000 tons containing	78,500
1800 to 1835. Copper ore raised 3,150,000 tons containing	167,000
1835 to 1855. Copper ore raised 4,370,000 tons containing	218,000
1855 to 1872. Copper ore raised 3,325,214 tons containing	201,431

From the last line we find the ratio of copper-ore to metal to be as 16·5076 to 1. The total copper obtained in Britain from the earliest times to 1872 is 869,431 tons and the total copper-ore obtained in the same period is, on the above ratio, 14,352,220 tons. From 1872 to 1913 we obtained a further 975,861 tons of ore containing 59,115 tons of metal. Hence, combining Hunt's and the Home Office figures, we find that

Britain has produced, up to 1913, a total of 15,328,083 tons of copper-ore, containing 928,546 tons of metallic copper.

Lead.—Hunt's figures for lead are: Total output of lead-ore from 1848 to 1872 was 2,298,163 tons, containing 1,653,932 tons of metallic lead. Adding the Home Office figures from 1873 to 1913, and assuming the same ratio of metal to ore as in the previous period, we find the output of lead-ore from 1848 to 1913 was 4,178,095 tons, containing 3,006,401 tons of metallic lead.

Hunt did not venture on an estimate of the output previous to 1848.

Zinc.—In the case of zinc, the sulphide (blende) has been preserved as of value for at least a century and a half. Of the carbonate (calamine) Hunt writes: "The quantity of calamine removed from the native deposits named cannot even be guessed at. It was regarded as a peculiar earth, not unlike alumina or magnesia, and its use was chiefly for the production of brass, although the brass-makers do not appear to have been aware of the fact that they were dealing with a metallic compound. At one time, without doubt, considerable quantities of calamine were obtained. These were generally superficial deposits, and they have been for the most part worked out."

The output of zinc-ore, obtained from figures given by Hunt and the Home Office, was 1,157,285 tons for the period 1856-1913, and this mass contained, on the ratio of ore to metal given by Hunt, 317,017 tons of zinc.

Iron.—It is uncertain when the working of iron was introduced into Britain. D. Mushet ("Papers on Iron and Steel, Practical and Experimental") thinks it probable that the Phœnicians introduced skilled iron-workers. The relics of Roman iron-workings have been already mentioned (p. 27). Mushet believes that the Danes brought improved methods of smelting

iron. Large heaps of scoriæ, called " Danes' cinders," are found in many places, with enough soil over them to grow large trees. Later on these " cinders " have been re-smelted. Their antiquity may be gathered from a statement by Dud Dudley, that decayed oaks of large size were to be seen on the heaps in 1620.

In many valleys in South Wales, scoriæ from old smelting-hearths are yet to be found, many feet below the present surface and covered with the remains of ancient forests that existed long before we have any authentic history of the iron trade in the district.

The early process of smelting iron-ore was by a wind furnace, almost the same as that at present used by natives in India and Africa. The ores were all mined at outcrop, and mostly by means of " races," or streams of water, directed onto the strata to wash away the clay and shale. Remains of " races " are still found at the heads of certain valleys. In South Wales the greater part of the coalfield was formerly covered with forests. Tops of hills, now bare and heath covered, were once heavily timbered. The ore was smelted on the mountain-side, in early times by wind-power, while later on the smelting was performed in valleys, in sites where water-power was available. The ore at outcrop was often oxidised, by exposure to air and moisture, into oxide of iron, and was not only easier to smelt, but in many cases gave a yield of 40-45% of iron. The country became more and more deforested until about 1740, when wood was so scarce that the manufacture of iron was nearly extinct in South Wales, and the whole output of Great Britain for the year was 17,350 tons.

According to Dud Dudley and Simon Sturtevant, in 1612 there were 300 furnaces in blast, smelting iron-ores with charcoal, and the average annual output of iron from the United Kingdom was 180,000 tons, using 144,000 tons of charcoal obtained from 17,310,000 cubic feet of timber. Dudley says that, about 1620,

there were 500 forges and iron-mills for refining the crude iron and converting it into malleable bars. These works produced on the average 75,000 tons per annum of bar iron, using 90,000 tons of charcoal from 10,732,000 cubic feet of timber. Adding this timber to the requirements of the blast-furnaces we find that 28,062 cubic feet of timber were used in the iron industry in a year. One acre of forest yields about 2,000 cubic feet, so that 14,000 acres were denuded of timber for the requirements of a single year. It is not surprising that wood became so scarce that, even so early as Elizabeth's time, Acts were passed restricting its use for iron-making. The output of iron consequently diminished until, about 1740, it reached a minimum as already mentioned. Dudley in 1619 succeeded in making 3 tons (or 7 according to another version) of pig-iron a week by using coke, but it was only in 1735 that Abraham Darby used it to such an extent that it was tried by British iron-makers.

W. S. Jevons, in "The Coal Question" (Edition 3, 1906), and R. Meade, in "The Coal and Iron Industries of the United Kingdom," give the production of pig-iron in Britain as follows:

1740	production	17,350 tons
1788	,,	68,300 ,,
1796	,,	125,079 ,,
1806	,,	258,206 ,,
1825	,,	581,367 ,,
1840	,,	1,396,400 ,,
1847	,,	1,999,608 ,,
1854	,,	3,069,838 ,,
1860	,,	3,826,750 ,,
1870	,,	5,963,510 ,,
1880	,,	7,749,230 ,,
1890	,,	7,904,214 ,,
1900	,,	8,959,691 ,,

Jevons adds that the earlier figures are doubtful, no allowance being made for furnaces out of blast. This means that the figures are probably too high.

The average output of a furnace in 1823 was 1,730 tons, in 1850 it was 1,824 tons, in 1840 it was 3,473 tons; each ton of iron that year requiring the burning of $3\frac{1}{2}$ tons of coal. In 1852 the output was 5,440 tons per furnace.

The introduction of coal gave a great impetus to the iron industry and led to the making of canals and tramways towards the end of the eighteenth century. Previously goods were carried by mules or packhorses. For example, Jevons records that, in 1580, Sir Francis Willoughby built Wollaton Hall, Nottingham, of stone brought from Ancaster, in Lincolnshire, on packhorses, which returned laden with coal in exchange.

In attempting to estimate the bulk of ores of all kinds which have been excavated in Britain from the earliest times we are faced by the absence of statistics until a fairly recent date; in the case of iron we have no figures before 1612. A consideration that helps us to fill the gap is the fact that for many centuries, and until fairly recent times, metallurgical processes were so primitive that a large proportion of the metal was left in the slags. The effect is to diminish the importance from a geological standpoint of the work of denudation performed by the ancient miners, for the ore they got is, in this manner, still supplying modern furnaces. Already considerable masses of old slag have been re-smelted, and this process will continue and probably increase in importance as the growth of metallurgical science enables poor slags to be worked profitably, until eventually the greater part has passed through the furnace a second time and the dross has been added to modern slag heaps. As an illustration of this principle we may point out that the Romans worked lead-ore extensively, but the slags and slimes they left have been re-worked to a great extent. Hunt says that between 1871 and 1880 about 9,000 tons of lead were got from old slags, some of which are probably not older than the sixteenth century. Similarly, iron slags

have been re-smelted, and even so late as 1915, an iron slag containing charcoal was being dug up some four miles north of Wolverhampton and sent to the furnaces.

We shall now give some notes on various iron-stone districts.

Hæmatites of Cumberland and the Furness Division of Lancashire.—Mr Bernard Smith notes that the history of iron-making in Furness may be divided into five periods. "The first, in which simple hearths were used, dates from the earliest times up to the dissolution of the [Furness] monastery in 1537. The second covers the short space of twenty-seven years when the industry was in the hands of private individuals, and ended in 1564 with the abolition of the bloom-smithies. After that year, until 1615-20, the manufacture of iron was carried on in bloomeries by the tenants of Furness Fells merely to supply their wants. The fourth period, that of the bloomery-forges, commenced about 1620 and closed in 1720, while the fifth began in 1711 with the introduction of smelting-furnaces and refinery-forges, and has not yet come to an end." The history of iron-making in Cumberland was similar, the earliest reference to mining relating to Egremont in 1179. The modern period began in 1750, when the first blast-furnace was built at Maryport. These early smelting-furnaces used chiefly "cinders" from the bloomeries as flux, although limestone also was used.

The hæmatite occurs in masses of widely varying shape, some being veins, others irregular masses with offshoots into the surrounding rocks, others ("sops") filling ancient swallow-holes. Some of the masses are found immediately under the Glacial Drift, others at moderate depths, which rarely exceed 500 feet. The masses near the surface were in some cases worked as open quarries (see p. 145), but the bulk of the ore has been obtained by mining.

Statistics show that from 1854 to 1915 the output of hæmatite from Cumberland amounted approximately

to 66⅔ million tons, and from Furness about 45 million tons, or a total of about 111⅓ million tons of ore. The curve in Mr Smith's book (p. 42) shows for Cumberland a rapid but fluctuating rise from about 300,000 tons in 1854 to about 1,100,000 in 1869, and thereafter no considerable changes. In Furness, however, there was a rise from about 350,000 tons in 1854 to about 1,400,000 in 1882, since which date there has been a fairly steady fall to a little over 300,000 tons in 1915.

In Furness, " underground working was carried on to a considerable extent as early as 1728, and up to 1780 exploration was entirely by shafts and levels. The shafts terminated on reaching solid rock and were rarely more than 30 yards deep " (Smith, p. 5).

It is probable that the total output of hæmatite from Cumberland and Furness does not greatly exceed 120 million tons in all.

It is frequently necessary to remove with the ore a great mass of sand or of clay. In places this is superimposed Drift, resting on the ore, but in other cases it occurs in pockets in, or around, the ore. The sand in some cases is in demand for steel-castings. Probably the material extracted with the ore is at least equal to it in bulk.

Assuming an average specific gravity for the ore of 4·16, the mass of 120 million tons implies a volume of 38,340,000 cubic yards, and the total bulk of material excavated amounts to 76,680,000 cubic yards.

The Forest of Dean.—The ore of this district is a mixture of hæmatite and brown hæmatite, and occurs under similar conditions to those prevailing in Cumberland. Principal T. F. Sibly writes that the Mineral Statistics show a total output of 3,865,000 tons of ore from this area between 1861 and 1917. The output was 99,416 tons in 1861, reached its maximum of 199,111 tons in 1871, and fell off rapidly to 5,830 in 1911. " Ancient mining from the outcrop probably robbed the Forest of Dean of as much iron-

ore as has been gained by all the mining from pits and levels. According to Nicholls the 'old men's workings,' as they are termed, were carried down to a depth of 160 yards in some places on the eastern side of the basin, and 50 yards on the western side. In the woods, much of the outcrop of the Crease Limestone is marked by labyrinthine excavations or 'scowles,' now rendered weirdly picturesque by the growth of great beeches and gnarled yews."

The modern period of deep mining dates apparently from the second or third decades of the nineteenth century. Usually pits have been necessary; but in the south-western part of the forest the valleys have allowed deep cross-measured adits to be driven. Some of these were made in the first instance to win coal from the Coal-Measures and later extended into the iron-ore. Outcrop mining by opencast excavations, slopes and shallow pits, has continued as a desultory accompaniment of deep mining.

The total ore extracted being roughly (assuming a specific gravity of 4·2) $2\frac{1}{2}$ million cubic yards, we may suppose a total excavation of twice this, say 5 million cubic yards, since the earliest times.

Weardale.—The iron-ore is mainly carbonate, which, near the surface, becomes a brown hæmatite. Mining is known to have been in progress as early as the twelfth century, but the modern method of working began some time between 1820 and 1840. The output soon developed to about 100,000 tons per annum, but then was rapidly superseded by Cleveland ore, reviving again in 1861. Continuous statistics are available from 1869 to 1916, during which time the total output was 1,365,297 tons. Allowing for the previous periods of working, probably about 3,000,000 tons of ore in all have been extracted. This is approximately 1,050,000 cubic yards, and allowing 100% for waste, the total bulk extracted may be about 2,100,000 cubic yards.

The Brendon Hills, Somerset.—The iron-ore was

probably mined by the Romans, whose coins have been found in some of the workings. The modern period of activity began about 1851, and from 1855 to 1909 the total output was 765,563 tons (less a few hundred tons from Exmoor). No less than twenty mines were opened during this modern period, and large dumps show that a considerable amount of rock was excavated, mostly sandstone, and shale more or less transformed into slate.

Cleveland District of Yorkshire.—The Cleveland ores consist of carbonate of iron, and occur in beds interstratified in the Jurassic rocks. In 1880, Mr G. Barrow made a careful estimate of the quantity of ore in the district. He estimated that the Main Seam contained 85,920 foot-acres, a foot-acre being the quantity of ore in a seam one foot thick and covering an acre.

According to Mr G. W. Lamplugh, the average thickness of the seam is from $4\frac{1}{2}$ to 11 feet, so if we take 9 feet as an average, we may regard the worked and workable iron-stone as consisting of a bed 9 feet thick and occupying an area of 9,547 acres. The part 11 feet thick is now almost worked out. There are other seams of iron-stone, of much less importance, below the Main Seam. Usually these are too thin to be worked; but at Grosmont the Pecten Seam, with an average thickness of $2\frac{1}{2}$ feet, is got, together with the overlying Main Seam, from which it is separated by a band of shale. From 2 to 7 feet below the Pecten is the Two Foot Seam, and 25 feet below that the Avicula Seam. This is 3 feet thick at Grosmont, where it is worked, but it thins to $1\frac{1}{2}$ feet elsewhere, with an average of 2 feet. The total output of Cleveland ore from 1854 to 1918 inclusive, as given in the Mineral Statistics, is 300,738,104 tons. The amount of waste material is probably only a small percentage of the bulk of the ore. About 10% of ore is left in the form of pillars. A cubic yard of ore weighs approxim-

ately 2 tons; hence about 150 million cubic yards have been excavated—say 160 million cubic yards, including some waste. This is equivalent to removing a seam 9 feet in thickness over an area of 50 million square yards; but allowing 10% for pillars left in the ground, the exhausted area is about 55½ million square yards, or about 11,480 acres, i.e., approximately 18 square miles.

Jurassic and Cretaceous Ores of the Midland Counties.—These are as follows:

	Geological Formation.	Distribution.
Claxby (or Nettleton) Iron-stone .	Lower Cretaceous	N.E. Lincolnshire
Northampton Iron-stone . . .	Lower Oolite	Mid. & S. Lincs., Rutland, North'ts.
Marlstone Iron-stone . . .	Middle Lias	Mid. & SW. Lincs & Leics.
Frodingham Iron-stone . . .	Lower Lias	N. Lincolnshire

The workable Frodingham iron-stone has an outcrop of about 7 miles in length between Coleby and Thealby, with a width from ½ to nearly 2 miles, and covering an area of nearly 8¾ square miles. In early days only the upper and more ferruginous part was worked, while the lower and more calcareous part was left. Allowing for the rejection of a small proportion of stone as unprofitable, the actual thickness worked averages 17 to 18 feet, and varies between a maximum of 30½ feet and a minimum of 2 feet at the extreme edge of the outcrop. The dip in the northern half of the area is only one in a hundred or about half a degree, and in the southern half it is even less. The cover is never over 12 or 15 feet thick, except at the extreme eastern limit, where one pit is working under a cover of 60 feet. It is stripped off by a steam navvy when very thick. The cover is probably on the average only 10 to 12 feet in thickness, for the

bulk of the iron-stone is got on a dip-slope with some blown sand resting on it, and the thicker cover referred to comes on very rapidly at the eastern margin, where it forms the escarpment of the higher beds. The blown sand is dumped in the old workings.

The Romans worked the ore to a trifling extent, and the slag from their furnaces is found buried under one or two feet of soil. After the Roman period the iron-stone does not seem to have been worked until 1859, when 2,000 tons were sold. By 1860 the amount had risen to 16,000 tons. The whole area of $8\frac{3}{4}$ square miles probably contained about 222 million tons of ore, assuming that one acre one foot in thickness gives on the average 2,400 tons, and that the average thickness of workable stone is 24 feet in the eastern section ($3\frac{3}{4}$ square miles) and 12 feet in the western section (nearly 5 square miles). The total output from 1859 to 1881 inclusive was about $7\frac{1}{4}$ million tons, and to the end of 1916 it was about $52\frac{1}{2}$ million tons. But the quantity of iron-stone removed is greater than this, for an appreciable amount was wasted as, at that time, unfit for use. Probably the iron-stone removed by the end of 1916 was about 60 million tons, leaving 162 million tons of ore under not more than 100 feet of cover. Of this amount 2,699,532 tons were got in 1917. Mr Wedd estimates the reserves that would need mining, i.e., under more than 100 feet of cover, at 336 million tons underlying the $9\frac{1}{4}$ square miles already explored, of which 10% would need to be left as pillars.

The 62,699,532 tons worked by 1917 would have a volume of about 48,146,000 cubic yards. If the average amount of cover, say 10 feet, was removed from the area from which the iron-stone, estimated at 17 feet in thickness, was obtained, the cover removed would be 28,321,000 cubic yards, and the total excavation therefore would be about 91 million cubic yards.

The Marlstone Iron-stone.—This covers about 7

square miles in Leicestershire and rather over 3 square miles in Lincolnshire, of which under 3 square miles in Leicestershire and about $1\frac{1}{8}$ square miles in Lincolnshire have been worked out, leaving reserves of rather more than 4 and $1\frac{1}{2}$ square miles respectively. The full maximum thickness of 15 to 16 feet may be got in a few cases; but a remnant of good ore not more than 3 feet thick is sometimes worked, and it is difficult to give an average. Leicestershire ore began to be worked in 1880, and up to the end of 1916 the total output was rather less than 20,300,000 tons, while the output of Lincolnshire during the same period was not more than 10 million tons. These figures give an average thickness of 5 feet 3 inches in Leicestershire and 5 feet 10 inches in Lincolnshire worked out, but the average covers tracts of barren ground or thin ore, e.g., Wartnaby, Holwell, and North of Eaton. The estimated average working thickness of 8 feet for Leicestershire and 7 feet for Lincolnshire gives reserves of about 42 and less than 20 million tons respectively, for the two counties. Hence the original total of workable ore was not less than 62 million tons in Leicestershire and about 30 in Lincolnshire. Probably a considerable amount of calcareous ore that could now be utilised was wasted. The cover varies from 1 to 2 feet of soil to a maximum, rarely reached, of 16 to 17 feet. The average may be taken as 6 feet. This waste is dumped into the old workings. The ore in Lincolnshire is self-fluxing when the lime-content rises to 12 or 13%. In the past the metal produced was mainly foundry-iron and to a less extent forge-iron, but recently the war has caused pigs for basic steel to be made.

On an average yield of 2,500 tons per foot-acre, the outputs for Leicestershire and Lincolnshire represent excavations of about 13 million cubic yards of ironstone in Leicestershire and $6\frac{1}{2}$ millions in Lincolnshire. The average thickness of the ore being 8 feet in

Leicestershire and 7 feet in Lincolnshire, and that of the cover being 6 feet, there has been a total excavation of nearly 23 million cubic yards in Leicestershire and 12 millions in Lincolnshire; or adding the two together the total amount quarried is nearly 35 million cubic yards.

Mr John Pringle, in the same work, states that in Northamptonshire, Oxfordshire, and Warwickshire, the thickness of the iron-stone is from 6 to 30 feet, with a probable average of 12 feet, over an area of 10,656 acres, which, at 2,500 tons per foot-acre, gives 319,680,000 tons. The ore deteriorates under a thick cover and is not likely to be worked under more than 14 feet. The cover is dumped on the old site after removing the ore. The iron-stone has been worked since 1859, but the returns have been united with those of other counties. They have grown, however, from 1,200 tons in the first year to 434,435 tons in 1917.

The Northampton Iron-stone.—The thickness of iron-stone in Northamptonshire ranges from 6 to 15 feet, with an average of about 10 feet. The ore extends into Lincolnshire and Rutland, the total area of the ironfield being about 132 square miles; but this includes some bad areas. The Romans worked it and have left slags. It is also mentioned in Domesday Book, and again in records from the time of Henry II. to that of Henry III. At one period Rockingham Forest vied with the Weald as a great iron producer; but fuel becoming scarce in consequence of the destruction of the forest, coal came into use and the Coal-Measure ores were opened up. As a result the industry entirely died out in the forest district for two centuries, and was not renewed till 1852. From 1855 to 1916 inclusive, the outputs have been: Lincolnshire $7\frac{1}{2}$ millions, Rutland $3\frac{1}{2}$ millions, and Northamptonshire $77\frac{1}{2}$ millions; total $88\frac{1}{2}$ millions of tons. For 1917 the outputs were: Lincolnshire 359,193, Rutland 371,854, and Northamptonshire 2,561,459 tons; a

total of 3,292,506 tons. The iron-stone is mainly got by opencast, but a part, probably from 5 to 10% of the whole, has been mined. The following table gives Mr Wedd's estimates of reserves.

	Total estimated area of unworked ironstone in acres.	Total iron-stone millions of tons	Opencast millions of tons
Lincolnshire . .	23,750	475	54 (at least)
Rutland . . .	5,900	118	nearly all opencast
Northamptonshire .	59,100	1,715	1,182
	88,750	2,308	

The cover, in quarries, varies from 1 or 2 to a maximum of 45 feet, and from 20 to 30 feet is quite commonly removed. Mining is resorted to when the cover reaches a thickness of about 40 feet, but mining and opencast working are carried on at the same depths. When the Lincolnshire limestone, which overlies the ore, is required, opencast working is the method adopted. The average cover removed is from 12 to 15 feet thick. At the present time, mining is carried on at only a few places, viz., near Lincoln, at Islip in Northamptonshire, and south of the Nene Valley; but there are also ancient mines, some of the earliest workings being of this kind. The average thickness mined is about 8 feet and about 10% is left for pillars.

Supposing that 10% of the output was obtained by mining, that obtained by opencast, to the end of 1917, was about 82,600,000 tons, which would be produced by removing a bed 10 feet in thickness covering 4,130 acres and having a volume of 66⅔ million cubic yards. This would involve the excavation of cover (at 12 feet average thickness) amounting to approximately 80 million cubic yards. The 10% mined would have a bulk of about 7,400,000 cubic yards. The total rock

excavated therefore, including both cover and ore, mined or quarried, is about 154 million cubic yards.

Claxby Iron-stone.—This ore was used by the Romans, who have left relics in the form of slag from their furnaces. Recently a little ore was worked at Hundon, north of Caistor, and at Tealby in Lincolnshire. The output from 1868 (5,000 tons) to 1881 was about 400,000 tons in all. The ore is about 6 feet in thickness.

Blackband and Clay Iron-stone.—The blackband and clay iron-stones of the Carboniferous System were in early days of the utmost importance, especially in Great Britain, but of late years the production of these ores has fallen off greatly. In South Wales the output fell from 1,100,000 tons in 1872, to 40,000 tons in 1890; in South Staffordshire from over 2,000,000 tons in 1866, to 39,566 in 1916; in Derbyshire from 493,000 tons in 1871, to 24,000 tons in 1890 and 116 in 1913; in Coalbrookdale from upwards of 300,000 tons to a little over 3,000. Scotland has yielded altogether 110 million tons of blackband, and in 1881 the output was about 1,402,700 tons of blackband and 1,192,375 of clay iron-stone (2,595,373 tons); but in 1894 this had fallen to 631,304 tons and this was nearly all clay iron-stone. A few years ago, however, a revival set in, and Scotland produced 800,000 tons of blackband and clay iron-stone.

At present North Staffordshire is the chief producer, yielding 859,244 tons in 1913. The total output of North Staffordshire between 1882 and 1916 was about 36 million tons, mostly from the eastern side of the coal-field. In Yorkshire the annual output has gradually fallen from 175,681 tons in 1882, to 15,592 tons in 1916. Previous to 1882 the output fluctuated between a minimum of 175,000 tons in 1859 and a maximum of 785,628 tons in 1868. Since 1885, it has fallen short of 100,000 tons.

Opencast working of Carboniferous iron-stone has been abandoned everywhere, although at one time important.

Total Output of Iron-stone in Britain.—In attempting to estimate the total quantity of iron-stone mined in Britain, we have the usual difficulty of the absence of statistics in early times. We can, however, estimate it by the production of pig-iron.

The output of pig-iron in Britain has been calculated from the outputs given on p. 39 for various years from 1740 to 1872, assuming the increase between the dates for which the output is given to be steady. The assumption is also made, on the authority of Berschlag, Vogt and Krusch, that ore yielded about 35% of pig-iron before 1860 and about 40% from 1860 to 1890. These data give us the output of iron-stone between 1740 and 1872. The outputs from 1873 to 1913 are taken directly from the Mineral Statistics. The figures for the period previous to 1873 will include pig-iron made from imported iron-stone, but this error is not a great one at that period, and the iron-stone won before 1740 introduces an error in the opposite direction. The total output from 1740 to 1913 inclusive is found to be 982,524,000 tons of iron-stone, say, 1,000 million tons of ore from the earliest times. This would imply about 332 million cubic yards of iron-stone (specific gravity being taken as 4·017). During the period from 1895 to 1913 the quantity of ore mined was approximately twice as much as that quarried; but whereas, in 1913, the quantity mined was scarcely $1\frac{1}{2}$ times, in 1895 it was about 3 times, and in 1887 more than $4\frac{1}{2}$ times that quarried. This change is due to the opening up of the Mesozoic ores between 1850 and 1860, and before that period the proportion quarried was very small. We may allow 60 million cubic yards for ore quarried, leaving 272 millions for ore mined. For waste we add 50%, so that the total

bulk of material excavated by mining may be regarded as about 408 million cubic yards.

Oil Shale.—Oil shale was at one time mined extensively at Burntisland, Fife, but now it is only mined in a roughly triangular area to the west of Edinburgh. The area measures about 8 miles along the base and about 16 miles from north to south. There are seven distinct groups of seams. The industry was founded in 1850 by James Young, who distilled a very rich shale called Torbanite, or Boghead. When this was exhausted, soon after 1862, other shales were distilled. Mining is carried on, sometimes by pillar-and-stall, sometimes by longwall, the former method being applied to seams of 6 to 10 feet in thickness, while longwall is usual for seams less than 6 feet. As to depth, one of the deepest mines, near Broxburn, reached shale at 720 feet, and one mine was as much as 1,600 feet deep. The output from 1873 to 1913 inclusive was 78,054,140 tons, and therefore 85,000,000 tons is probably about the total amount excavated since the industry commenced. Allowing a specific gravity of 2·6, this would mean the excavation of 41 million cubic yards, apart from any waste from shafts, etc. Waste, however, in thick seams such as these is not great, and we will allow 9 million cubic yards for it. Oil shale waste is discussed on p. 206.

Rock-salt.—The quantity of rock-salt mined, as such, is comparatively small, but a great deal is pumped up in solution as brine. To avoid repetition the output of salt will be discussed in the chapter on subsidence (p. 146), because the method of extraction and the thickness of the salt beds cause serious subsidences.

Slate.—The output of slate between 1874 and 1913 was 16,877,961 tons, of which nearly a third was mined. As slate has been in use since the Middle Ages we shall not exceed the truth in estimating the total output at 20,000,000 tons, of which, say, 6⅔ millions

were mined. Allowing fourteen times the bulk for waste, the quantity mined would be about 100 million tons of slate, good and waste, or about 47 million cubic yards.

Gypsum.—The output of gypsum from mines, from 1888 to 1913, was 4,273,868 tons, so that the total output from gypsum-mines may be about 6,000,000 tons, or about 360,000 cubic feet. Allowing for three times the bulk of waste (chiefly Keuper Marl) we have a total excavation of about 8,700,000 cubic yards.

Chalk.—Anyone walking over the chalk districts will notice saucer-shaped depressions scattered over the fields. Until recently it has been the custom to mine chalk for " marling " the land wherever the surface is covered by clay deposits. A shaft having been sunk through the overlying drift, a man descends and digs out the soft chalk round the shaft until a large bell-shaped chamber is hollowed out. In Buckinghamshire and Hertfordshire, where the Upper Chalk frequently does not exceed 50 feet in thickness and has at its base the massive Chalk Rock, these shafts are often as much as 50 feet deep, the Chalk Rock forming the floor. The arched roof of chalk stands well, and enough chalk to marl a moderate-sized field can be brought up from a single shaft. When the mine has yielded as much as it is safe to extract without danger to the miners, the shaft is filled up with soil shovelled in from round about the shaft, thereby initiating the saucer-shaped depression. At other times timbers are laid across the shaft near the top and soil laid over these, entirely hiding the hole for many years. In time percolating water weakens the shaft's sides and the depression increases. If the shaft has been simply covered over with timber and soil, the timber rots sooner or later and the ground falls in. In this way cattle have been suddenly engulfed without warning into holes of which the existence was entirely unknown. The depression

extends, as the shaft and probably the roof of the mine give way, until a hollow of round or oval shape, often 30 or 40 yards across and perhaps 10 or 20 feet deep, forms over the old bell-pit or Dene-hole. In Buckinghamshire and Hertfordshire these depressions are very numerous, and at first sight are likely to be mistaken for the remains of old quarries. They are most numerous at the margin of the drift-deposits. Bell-pits are still occasionally made (one was seen in process of construction at Lee, near Wendover, in 1911, and several near Hatfield, Hertfordshire, in 1913), but they are now rare, as the custom of marling the land is going out. The great number of the depressions in the fields shows the extent to which the marling was formerly carried on.

Arthur Young, in 1804, gave details of the method of digging the pits in use in Hertfordshire at that date. It was usual to make the shaft in the middle of an area of about 6 acres which it was proposed to chalk. The shaft was sunk to a depth of from 20 to 30 feet and 3 horizontal galleries dug at the bottom. Each pit produced enough material to chalk the surrounding 6 acres, allowing an amount varying from 15 to 100 loads per acre, with an average of about 50 loads. A load is described in one place as 18 barrowfuls and in another as 22 bucketfuls or heaped bushels. A bucketful appears to be $1\frac{1}{2}$ bushels. In modern agriculture a cubic yard is reckoned as 7 barrow loads. If this held in Young's time, each acre received about 129 cubic yards of chalk every ten or twenty years, usually ten. If chalk was not reached at the depth of 20 feet the hole was filled up and another place tried.

The total amount of chalk removed in this way must be very great. In the area of 54 square miles covered by the six-inch Ordnance maps, Buckinghamshire 42, 38, and 39 SW., and surveyed by the author, the number of chalk-pits and bell-pits shown by

depressions together number 353. It is practically impossible to separate old chalk-pits from bell-pits, and the number of the latter is greater than appears, for an unknown number have not yet fallen in. About half the 54 square miles is covered by bare chalk and the rest by drift and valley gravel. The average number of pits per square mile is: in Sheet 42 Bucks. 6·29; in 39 SW. 6·67; in 38 Bucks. 6·75, and the average for the 54 square miles is 6·537 per square mile. The pits are therefore rather uniformly scattered. The area lies between High Wycombe and Wendover, and includes Great Missenden and Chesham.

The open quarries may be one-third of the whole number, but it is not easy to distinguish an old subsidence round a shaft from an overgrown quarry, and, excepting two or three quarries, the two kinds leave hollows of much the same average size. This average is a saucer-shaped depression, somewhat oval, about 40 yards by 35 yards, and about 4 yards deep. The loss of material represented by these depressions amounts to about 29,500 cubic yards per square mile. In the case of the bell-pits the depression does not represent all the chalk removed, for when the shaft falls in the radial galleries often remain sound. Moreover the shaft-filling is composed of material loosely packed, and for that reason the volume of subsidence is smaller than that of the cavity below. We may therefore estimate the quantity of chalk mined for marling the land over an area of unknown extent, but certainly some hundreds of square miles, at 30,000 cubic yards per square mile.

Chalk is by no means the only rock used for "marling" the land. Many of the clay formations contain a percentage of lime, usually in the form of fossils, and they have been extensively used for marling. One of the most extensive geological formations in England is the Keuper Marl, and old marl-pits are scattered abundantly over its outcrop. R.

Grantham has recorded that, in reclaiming the sand of Delamere Forest, Cheshire, about 1856, parts were cleared, marled, and let on farming leases. The Houndslow Farm, of 248 acres, had 29,000 cubic yards of Keuper Marl spread over it; and the Long Ridge and Glover's Moss Farm, of 800 acres, was marled from a bed of dull red boulder-clay found under the north-eastern slope of Eddisbury Hill. From this lenticular mass, 12 to 15 feet thick, 87,228 cubic yards were carried for over two miles and spread over the farm. After a few years the marl has been found to form a layer a few inches below the subsoil.

Marl-pits in all formations are included in the estimate on p. 77 of total rock quarried, for it has been found impossible to separate the depressions representing chalk-mines from the much greater number of open marl-pits.

De la Beche, writing in 1839, stated that sea-sand and blown sand, on the Cornish coast, had been employed as far back as 1602 for " marling " the land. In this case the lime is derived from the fragments of shells scattered through the sand. The quantity spread on the land is very considerable, for 4,000 horse-loads have been taken from Bude on a single day. A good road was made to Trebarwith Sands, near Camelford, purposely for conveying the sand into the interior. It was estimated, in 1836, that 100,000 tons per annum were taken from Padstow harbour, in addition to the large amount taken from the neighbouring sand-dunes. In 1811, the amount removed from the harbour was 54,000 cartloads. De la Beche considered that, reckoning 14 cubic feet to the ton, about 5,600,000 cubic feet (say 200,000 cubic yards) of sand, containing from 40 to 70% of comminuted shells, was annually conveyed from the Cornish coast and spread over the land.

Extent of Underground Workings.—A Report on

the lengths of the Underground Workings and Passages in some of the principal Collieries and Metalliferous Mines in England and Wales, was presented, in 1881, to the House of Commons. It shows that in 294 mines there were 1,540 miles 224 yards of workings passable by man, in addition to 486 miles 1,589 yards passable by horses and trams. All the above were disused; but there were in use, in addition, 2,298 miles 656 yards passable by man, besides 1,758 miles 1,420 yards passable by horses and trams. The total length of workings, comprising both used and unused, passable by man was 3,838 miles 880 yards, and passable by horses and trams was 2,245 miles 1,249 yards.

The figures for disused workings must be much less than the original length of the passages, for many are blocked by falls of roof, filled by goaf, or flooded, and therefore impassable. The 294 mines referred to form a small part of the total number. An official list of plans of abandoned mines, deposited at the Home Office up to the end of 1911, contains the names of no less than 5,283 mines in England and Wales, and comprises all mines abandoned since 1873 with some of earlier date, but none is earlier than 1822.

It is impossible even to guess at the total number of mines in England and Wales in use and abandoned. Some indication of the great number of disused shafts is given by the statement in the Mineral Statistics for 1854, that there were in South Staffordshire and Worcestershire, at that time, more than 500 collieries with at least 2,000 pits in full work. Also in the three square miles shown on the eastern half of six-inch Ordnance map, Staffs. 62 SE. the sites of no fewer than 92 coal-shafts are marked. In 1859, the total number of collieries in England and Wales was 2,450 (South Staffordshire containing 425), Scotland 417 and Ireland 74. It appears from the above figures for

1854 that the shafts in use were about four times as numerous as the collieries. Many mine-shafts have been entirely lost sight of. Occasionally one, whose existence was unknown, is disclosed by falling in, sometimes in a public street; or old workings may be unexpectedly broken into during mining operations. Old shafts are also scattered over the metalliferous districts, such as Devon and Cornwall, where they are to be found on the moors or in woods, entirely masked by undergrowth.

The older workings must have been, on the whole, considerably nearer the surface than those now worked. Before James Watt invented his steam engine in 1769 a shaft 200 feet deep was uncommon. In the Report to the House of Commons, in 1881, cited above, the average depth of the shaft in the case of 310 of the principal collieries and metal-mines was found to be 845·8 feet. Professor Hull, in 1890, estimated that the average depth at which coal was obtained in the British Isles was then 1,050 feet. Minerals are dug from increasingly greater depths as the mines become exhausted. Dr. Walcot Gibson thinks that at present the average depth at which coal is being got, in this country, is about 1,500 feet. The underground passages occur therefore at different depths, and there are frequently several levels in a single colliery.

The sectional areas of underground workings vary considerably. Up to about 1800, shafts were commonly square and not more than 8 feet across; but since that date they have been increased and made circular. The diameter of the circular shafts now used is about 18 feet. The workings passable by man probably averaged a square yard, while those passable by horses and trams varied from about 1 5/6 square yards to perhaps 30 square feet in cross section. The larger passages are excavated only partially in the coal.

These underground workings are interesting from several points of view. They represent a mass of rock brought up to the surface from a considerable depth; they provide reservoirs and new channels for the circulation of underground water, and allow atmospheric gases to penetrate a long way below the surface of the earth, where they produce weathering similar to that at the surface; and they frequently cause subsidences after they have become derelict.

With regard to the first point, the rock excavated is largely coal, and is included in the estimate on p. 24 of the total coal mined in the British Isles. Allowing for shafts, trials, the larger passages only partly in the coal, and various excavations where the seam is thin or the roof is tender, or when faults are being driven through, and also for sandstone and fireclay obtained from the mines, it is probable that, on the whole, the total amount brought to the surface in connection with coal-mining, since the earliest times, is about one and a half times the bulk of the coal.

The second question, the underground circulation of water in mine-workings, is deferred to the chapter on Circulation of Water (p. 279) and the third question to that on Subsidence (p. 127).

Relative Bulk of Rock Mined and Quarried.—It is only possible to separate the output of mines from that of quarries after the passing of the Quarries Act in 1884. Even after that date there was a confusion between mines under the Coal Mines Act and those under the Metalliferous Mines Act, for until 1897 we find the bulk of the iron-stone workings under the former Act, even when the mines lay outside any coal-field.

Taking the nineteen years from 1895 to 1913, inclusive, that is to say from the date of separation of the statistics until the last year before the war, we may compare the rocks and minerals obtained from mines with the quantities obtained from quarries

(p. 73). The quantities are given first in tons, as in the Mineral Statistics, and these are turned into cubic yards by calculating from the appropriate specific gravity.

ROCKS AND MINERALS MINED DURING THE NINETEEN YEARS, 1895-1913.

	Tons.	S.G.	Cubic yards.
Coal . . .	3,829,935,396		3,829,935,396
Iron-stone . .	180,861,603	4.017	53,874,858
Gypsum . .	3,461,578	2.75	1,673,559
Rock-salt . .	36,289,956	2.22	19,560,799
Slate . . .	2,605,198	2.83	1,223,559
Barium Compounds	593,913	4.5	175,473
Fluorspar . .	344,089	3.4	141,963
Zinc Ore . .	384,523	4.9	127,809
Tin Ore . .	131,653	7.0	25,005
Lead Ore . .	568,410	7.5	100,762
Copper Ore . .	117,827	4.2	37,298
Arsenical Pyrites	70,436	6.0	15,921
Iron Pyrites (not from collieries) .	45,840	5.0	12,189
Gold Ore . .	211,314	2.7	104,055
Oil Shale . .	48,630,210	2.6	24,878,477

In addition there was an output of 58,952,082 tons of clay, some of which is fuller's earth and china-clay, but the greater part is fireclay, obtained from coal-mines. The output of alum shale in the same period was 121,025 tons, all derived from between coal-seams. Fireclay and alum shale are here included in the allowance for waste from collieries (see below), and so are not placed in the table, while china-clay is left out because only a proportion, difficult to estimate, is mined. The quantity, however, would not seriously affect our totals.

In the following table the second column gives the percentage of waste material estimated to have been

excavated in the extraction of the valuable mineral. The third column gives the total bulk excavated.

ROCKS AND MINERALS MINED DURING THE NINETEEN YEARS, 1895-1913.

	Cubic yards.	Percentage of waste	Volume excavated in cubic yards.
Coal . . .	3,829,935,396	50	5,744,903,094
Iron-stone . .	53,874,858	50	80,812,287
Gypsum . .	1,673,559	300	6,694,236
Rock-salt . .	19,560,799	25	24,450,998
Slate . . .	1,223,559	1,400	18,358,830
Barium Compounds	175,473	100	350,946
Fluorspar . .	141,963	100	283,926
Zinc Ore . .	127,809	1,500	2,044,944
Tin Ore . .	25,005	10,000	2,525,505
Lead Ore . .	100,762	2,600	2,720,574
Copper Ore . .	37,298	1,000	372,980
Arsenical Pyrites .	15,921	2,000	334,341
Iron Pyrites (not from collieries) .	12,189	1,750	225,495
Gold Ore . .	104,055	—	104,055
Oil Shale . .	24,878,477	22	30,351,742

The waste in the case of lead, zinc, arsenic, and pyrites, is assumed to be nine times the weight of the ore, and the total mass is assumed to have the specific gravity of calcite, i.e., 2·7. Barium compounds, fluorspar and lead-ore are usually found together. As the waste from lead-ore frequently yields both barium compounds and fluorspar, these latter are considered to produce only 100% of waste.

Comparing the total excavation from mines, 5,914,533,953 cubic yards, within the nineteen-year period with the estimate (p. 74) of the total from quarries during the same period, it is noticeable that the bulk mined is more than six times the bulk quarried. This somewhat surprising fact is due to the enormous preponderance of the coal output over that of all other minerals, for if coal were excluded the bulk of materials

quarried would exceed that mined in the same period by three and a half times. In early days when minerals were obtained nearer the surface than now the proportion of mined to quarried material may have been somewhat smaller than at present, but probably not appreciably, for the materials now mined could only have been obtained in quarries to a limited extent. Coal excavated at the surface, for example, is nearly worthless.

Total Bulk Excavated by Mining.—Next we shall endeavour to estimate the bulk of rock removed by mining operations since the earliest times.

The total copper-ore believed to have been obtained in Great Britain is 15,328,000 tons (see p. 37). The estimate, by J. H. Collins, of the copper-ore and total excavation in the mines of Cornwall and Devon may be applied to all the British copper-mines, which on the same method of calculation will have yielded 96,298,000 tons of rock and ore, or assuming an average specific gravity of 2·7 for the waste materials, the total bulk excavated from British copper-mines is found to be about 44,712,000 cubic yards.

In the case of lead Mr R. G. Carruthers estimates that the raw materials excavated in modern English mines contain about 10% by weight of galena. Probably, in early days, the ore obtained was richer than that now got. The total output of lead-ore from 1848 to 1913 being about 4,178,000 tons (see p. 37), we shall assume that at least six million tons of lead-ore have been dug up since the earliest times. The raw material excavated would therefore weigh about 60 million tons. Assuming a specific gravity of 2·7 (that of calcite) for the whole mass, the bulk removed would be 29,545,000 cubic yards.

For tin we have Collins's figure of 6½ million cubic yards of rock excavated, without reckoning the alluvial deposits turned over and estimated, from data given by him, at 300 million cubic yards.

In the case of the other metallic minerals we shall assume that the total quantity excavated is ten times the weight of the ore, as in the case of lead. The output of zinc-ore in Britain for the period 1856 to 1913 was 1,157,285 tons, and therefore an estimate of 1,250,000 tons from the earliest times does not seem excessive. This gives a bulk excavation of 6,443,750 cubic yards.

For the less important ores the following rough estimates are given, arrived at in the manner adopted for lead and zinc:

	Cubic yards.
Manganese (output 1873-1913 was 207,809 tons), including waste, about	1,000,000
Ochre and Umber (output 1873-1913 was 483,341 tons), including waste, about	300,000
Arsenical pyrites (output 1873-1913 was 191,534 tons), including waste, about	1,000,000

In the case of barium compounds and fluorspar the waste is estimated at only 100% of the minerals, because they so frequently occur as gangue with lead-ore and in those cases the waste has been estimated in the figures for lead.

For gold-ore, which is quartz with a few pennyweights of gold per ton, no waste is allowed.

Barium compounds (output 1873-1913 was 1,097,608 tons), total excavation, including waste, is about 500,000 cubic yards.

Fluorspar (output 1873-1913 was 476,755 tons), total excavation about 300,000 cubic yards.

	Cubic yards.
Gold ore (output 1873-1913 was 258,398 tons), total excavation about	130,000
Pyrites, not obtained from coal mines, about	300,000
Oil shale, total excavation, including waste, is about (p. 52)	50,000,000
Slate, total excavation, including 1400% of waste, is about (p. 53)	47,000,000
Gypsum, total excavation, including waste, is about (p. 53)	8,700,000

For chalk, assuming 300 square miles have been mined at the rate of 30,000 cubic yards per square mile (p. 55) the total excavation is about 9,000,000 cubic yards, but this is included in the estimate for quarries (p. 77), as the depressions representing chalk-mines cannot be separated from open quarries.

In the case of rock-salt, the total amount removed from Cheshire is about 71½ million cubic yards (p. 153), and there is no waste rock to excavate. The output from the Middlesbrough District is 2,916,000 cubic yards (p. 154). That of Worcestershire, from 1859 to 1918, was 11,650,123 tons (p. 155), and therefore 13 million tons, equal to 8,125,000 cubic yards, does not seem an excessive estimate for the salt removed since earliest times. The salt output of Staffordshire, from 1873 to 1913, was 752,075 tons, and before 1873 it was probably trivial, so we will take 800,000 tons as the total output, equal to about 500,000 cubic yards. The Fleetwood District has lost about 5⅓ million cubic yards in all (p. 155). The total loss of rock-salt therefore, in connection with the salt industry, is about 88,274,000 cubic yards.

For iron-stone the total excavation (p. 52) is about 408 million cubic yards.

The total output of coal has been estimated, from 1500 up to the end of 1913, at 12,667 million cubic yards (see p. 24), and the total bulk of rock and mineral excavated is, say, one and a half times that amount (p. 24), or 19,000 million cubic yards. In this colossal figure we may include fireclay, ganister, alum shale, etc., which are obtained from collieries. The bulk of the clay and sandstone mined, as distinct from that quarried, comes from collieries, and so we shall regard them as included in the above figures for colliery waste products.

Tunnels are really mines; but it is not easy to separate the material so excavated from that obtained from open cuttings on railways, canals, etc. In the

case of canals the excavation from tunnels, in England and Wales, is about 1,305,400 cubic yards (p. 83), but the larger volume, from railway-tunnels, has not been estimated. These two items are included in the total excavation from railways (p. 81) and canals (p. 83). Tunnels are also sometimes made for subways (p. 169), or for watersupply, as in the case of the Liverpool supply from Vyrnwy. Tunnels are not included in the following figures.

The total volume excavated from mines, since the earliest times, is therefore of the order of 19,692,000,000 cubic yards. This is equivalent to a mass of material spread over 100 square miles to a depth of 189½ feet. Spread uniformly over the area of England and Wales (58,186 square miles) it would cover the country to a depth of 3·9 inches.

Quarries.—Excavations open to the sky are called quarries, in contradistinction to mines, which are excavations with a natural roof. Strictly speaking, road- and railway-cuttings are quarries, while tunnels are mines, but these are discussed separately.

Quarries existed in Britain even in Roman times, as witness London Wall, built of Kentish rag, and Pevensey wall, of sandstone from Eastbourne. In mediæval times local stone was generally used in important buildings such as castles or churches; ordinary houses were of wood or of clay. If the locality did not supply the stone it was almost essential that it should be got from a place from which it could be brought by water-carriage, for roads were for the most part too primitive to be used for transport. Barnack quarries, near Stamford, supplied the Fenland monks with stone for their churches; York Minster was built of stone brought down the Wharfe, Aire and Ouse. London and Westminster were mainly supplied from Reigate and Chaldon, in Surrey, and Maidstone in Kent. Bath stone from Box, Wilts., was sent to Winchester Palace in 1221. It is recorded

that, in 1367, Rochester, to build its castle, bought 55 tons of stone from Beer, Devon; 62 tons from Caen, France; 45 tons from Stapleton, Yorks; 44 tons from Reigate; and a large quantity from Boughton. Kent stone was also in demand in the fourteenth century for cannon balls, of weights varying up to about 600 lbs. Slates were in use as early as 1296, for in that year they were used for mine-buildings at Martinstowe. The flags called Collyweston Slates were used for roofing as early as the Roman period. The earliest ornamental stones to be used for interior decorations were Purbeck Marble, which came in about the end of the twelfth century and was in demand for about two hundred years, and alabaster obtained from near Tutbury, in Staffordshire, and Chellaston, Derbyshire. The waste from the alabaster was burnt into plaster of Paris.

The quarries for local use were small. Stone was difficult to obtain in the absence of modern explosives, and the demand was very limited. A great deal of stone was readily obtainable for walls or for throwing into ruts on the roads by the mere collection of loose blocks, which, it must be remembered, have been diminishing in number ever since Man began to take to settled habitations. Roman remains also served as "quarries," and were pulled down for the building of new structures even up to quite recent times. With the enormously improved facilities for transport brought about by the introduction of railways there has been a tendency to neglect local quarries and to obtain stone from a moderate number of large ones capable of supplying a large district; or even the whole country. Mr H. B. Woodward, who noticed this tendency and that the number of open sections every year decreased, wrote ("The Jurassic Rocks of Britain," Vol. III, p. 12): "Railways have indirectly been the cause. It arises partly on account of the introduction of hard road-metal to districts and

villages which in former years depended entirely on such local stone as was to be found. The ' Mendip granite ' (as the Carboniferous Limestone is commercially miscalled), the Hartshill stone, the Charnwood Forest and Mount Sorrel rocks, and the Clee Hill Dhu stone, are responsible for the closing of many quarries in Jurassic areas. In places, too, the slag from iron-furnaces is employed as road-metal. Again, at the larger brickyards like those near Peterborough, where machinery is extensively used, bricks of better quality and cheaper in price can be made than is the case at many a small out-of-the-way brickyard. Consequently many of the latter have been abandoned, and more are likely to be. Moreover, owing to social changes, comparatively little building is carried on in the villages compared with what took place in times gone by . . . it is probably only within the last thirty years, and particularly within the last fifteen years, [this was written in 1893] that so many pits and quarries have been closed."

The volumes of materials excavated from a few important quarries in Britain have been estimated in order to serve as illustrations of the amount of denudation represented by quarries of the largest size.

For the first example, that of the Parys Mt. Copper Mine, Anglesey, I am indebted to Dr E. Greenly, who has allowed me to examine his detailed geological maps and has given me additional information. The mine (really a quarry) was commenced in 1768. The main opencast is about 1,250 feet long, with an average width of about 340 feet and average depth of 120 feet (the depth varies from 100 to 200 feet). The volume of rock removed is therefore about 1,888,800 cubic yards. The so-called Mona Mine adjoins the main opencast, and is really part of the Parys Mine. It is an opencast cut in the form of terraces, and the depth is about 200 feet on the north side and only 100 feet on the south side. The rock

removed is estimated at 245,000 cubic yards, and the two open-casts together represent the removal of about 2,134,000 cubic yards. The rock is a very hard silicified shale impregnated with copper. The hill is nearly covered with dumps built of loose lumps of rock. To the north are also dumps from the shafts sunk at a later date to reach the underground veins. Very little mining is now carried on, but water is pumped from the mine and the copper in solution is precipitated by iron. The solution then contains ferrous sulphate, and is exposed to the air until the iron is precipitated as ochre.

The second example is Delabole Quarry, Cornwall. This is worked for slate, and is said to date back to the reign of Queen Elizabeth. The average depth is about 500 feet, and the greatest depth is about 600 feet, with a boring to about 700 feet. Roughly rectangular in shape, it is 400 yards long by 280 yards wide, with an incline and terraces at the south end. The north and higher end has a surface level between 600 and 700 feet above Ordnance Datum, and therefore the bottom is nearly at sea-level. The volume of slate, etc., dug out is estimated at eighteen and two-third million cubic yards. This quarry is probably the deepest in Great Britain. Borlase, in 1758, gave its dimensions in his time as 300 yards long, 100 wide, and 80 deep. If rectangular, the excavation in 1758 was 2,400,000 cubic yards. There are many other large quarries, in the same formation, along the coast, from which the rubbish is thrown into the sea, where it is quickly moved by the waves and washed up near Bude.

Of the pits in the Etruria Marls of the Coal Measures, near Ruabon, North Wales, which supply the clay for terra-cotta bricks and tiles, six pits, practically all there are, have yielded about 2,682,000 cubic yards of rock. The largest are the Pen-y-bont, 200 × 250 yards and 50 feet deep, yielding approxim-

ately 833,000 cubic yards; and the Hafod Red Brick Works pit, which has a cavity of about 753,000 cubic yards.

The famous road-metal quarries of Hartshill, Nuneaton, are excavated in a sedimentary Cambrian quartzite, somewhat metamorphosed and containing shale bands (which are waste) and some igneous intrusions. I am indebted to Mr T. Eastwood, who has investigated the geology, for data on which the following estimate is based. The quarries are situated in a strip of flattish high ground, rising sharply for about 150 feet above the valley, and $2\frac{2}{3}$ miles long by about 250 yards wide. The average depth of the quarries is about 50 feet, some being much more and others a good deal less. From the six-inch maps the volume excavated is calculated at about 5 million cubic yards. In addition there are old pits near by filled in with waste and not considered in the figures given. There are large dump-heaps in front of the quarries on the slope of the hill.

Some of the china-clay pits of Cornwall and Devon are very large. One in the St Austell district has an area of 6 acres; the greatest depth is 150 feet, and the overburden is 20 to 60 feet in thickness. The daily haul is 220 tons, including overburden.

The Charnwood Forest granite quarries are numerous and large. They are situated in hills of Pre-Cambrian igneous rocks that project through the Trias and Drift. After quarrying, what was a hill becomes a hole in the ground. This is particularly the case at Mountsorrel Quarry.

The Rubislaw granite quarries are situated close to Aberdeen. They were opened in 1787, and the excavations now cover 7 acres. The depth of the quarry in 1901 was 270 feet, and the output about 100,000 tons annually. The Kemnay Quarry, in the same county, was 200 feet deep in granite in 1902. The floor was at that time formed by an intrusive

sheet of basalt 5 to 4 feet in thickness, which was being removed to reach the granite below. The output is about 60,000 tons annually, and the quarry is said to have yielded about 8 million tons of granite since it was opened.

The Jurassic Iron-stone workings are situated on flat lands immediately in front of gentle escarpments, and the result of the quarrying is to lower large areas of the flat by about 9 or 10 feet. The six-inch maps of the Geological Survey enable some of the excavations to be measured. In the Vale of Belvoir, Leicestershire, there are four chief open-workings in iron-stone.

Staveley Co., White Lady Quarries.—Over an area of 75,000 square yards the ground has been lowered by about 10 feet. Nett excavation, about 250,000 cubic yards.

Eastwell Lodge, Eastwell.—The lowering of the surface is from 7 to 10 feet, say 9 feet on the average, over an area of about 810,000 square yards. Nett excavation, 2,430,000 cubic yards.

Between Eaton and Stathern.—The area excavated is about 1,575,000 square yards; the average lowering of the surface is about 10 feet. Nett excavation, 5,250,000 cubic yards.

Wartnaby.—The area excavated is about 2,360,000 square yards, the average lowering of the surface about 10 feet. Nett excavation, 7,770,000 cubic yards.

The total volume removed from these four areas is about 15,700,000 cubic yards nett. The nett excavation is much less than the bulk of rock removed, because the cover is thrown into the quarries and partially fills them up with loose debris. The areas are polygonal, and are sometimes divided by a road or a railway, which stands as if on an embankment, although really representing narrow strips of the original surface.

Looking at the figures in another way, they represent an area of 1,135 acres that has been lowered, in the case of 167 acres, by 9 feet, and of 968 acres, by 10 feet. These figures ignore small excavations.

These illustrations will give some idea of the dimensions reached by quarries in Britain. In addition to excavations worthy of the name of quarry, there are innumerable small pits (many now ponds) dug for various materials, such as chalk or marl for putting on the land; gravel, sand, and clay for local use; and small quarries opened temporarily to provide stone for building a house. There are also remains of old quarries now largely filled up and overgrown. Collectively these small excavations represent a very large bulk of rock. In order to form an idea of the amount of material they have yielded, the number and volume of all the pits and ponds within an area of 12 square miles was investigated. Each pit was roughly gauged by measuring it on the large scale Ordnance map; those not shown on the map by pacing the length and estimating by eye the average depth. The district examined was a rectangle, extending 3 miles east and west and 4 miles north and south, and forms the area covered by the six-inch Ordnance Survey maps, Staffordshire 56 NW. and 50 SW. The district is an agricultural one, without towns, but containing the large village of Brewood and two or three hamlets. The geological formations are Keuper Marl and Sandstone, and Glacial Drift, and the materials dug are marl to put on the land, sandstone used locally for some houses and for a bridge over the canal, a little clay for bricks, and some sand for use in building. There are, however, no large quarries. The number of old pits, many of them now ponds, is exactly 300, and the total volume excavated is estimated at 2,336,935, say $2\frac{1}{3}$ million cubic yards.

It is of course desirable to measure other areas in

a similar manner; but the area in question is a quite typical piece of English country in which old pits are neither rare nor specially numerous, and until more evidence has been collected it may be used to give some idea of the amount of material dug from minor excavations. It is to be noted that cuttings on roads, railways, and canals are not included. The figure gives an average of 194,744 cubic yards per square mile, and could be applied to urban as well as rural districts, for every town covers similar old pits filled in with waste as the town grew.

Some idea of the amount of materials—soft or hard—excavated in the past may be obtained from these figures. At the rate of 194,744 cubic yards per square mile, the volume excavated in England and Wales (area 58,315 square miles) is 11,356,496,360 cubic yards, say 11,360 million cubic yards. This figure is a first, very rough, approximation to the amount of quarrying done in the past. It will be below the truth, because many small quarries and pits have doubtless been so completely obliterated in the course of ages that they escape notice; nevertheless, the process of obliteration being a slow one, probably the proportion of pits now entirely lost sight of is not great. Quarries now worked are not included, nor are mines, wells, road-cuttings, and other excavations, all of which should be added to find the full measure of artificial denudation.

To get a very rough approximation to the quantity of rock excavated during a particular year in the United Kingdom, we may add together the quantities given in the Mineral Statistics, and allow an additional amount, first, for rock obtained from quarries not exceeding 20 feet deep, and secondly, for waste materials.

The outputs of rocks and minerals for the nineteen years, 1895-1913, recorded in the Home Office Statistics, derived with a few exceptions from quarries

over 20 feet deep, are as follows: (The period is chosen because most of the records begin in 1895, after the passing of the Quarries Act, and 1913 was the last year of normal outputs before the war.)

Output	Tons.	S.G.	Cubic yards.
Gravel and sand . .	37,828,279	1.7	29,382,000
Clay (quarried) . .	208,680,376	1.93	143,718,000
Sandstone (quarried) .	92,278,524	2.2	55,755,000
Igneous Rocks . .	103,460,238	2.95	46,619,000
Limestone, other than chalk . . .	225,477,097	2.65	113,268,000
Chalk	82,745,887	2.55	43,135,000
Chert and Flint (including a little mined) .	1,497,018	2.58	771,000
Gypsum (quarried part)	902,095	2.75	436,000
Celestine . . .	288,023	3.96	97,000
Slate (quarried) . .	6,979,045	2.83	3,278,000
Iron-stone (quarried) .	91,446,933	4.017	30,370,000

The last column gives the volume in cubic yards to the nearest thousand, and is calculated from the average specific gravities given in the third column.

The output from a quarry is only a part of the material excavated there, because there is always some waste. In the case of building-stones all the upper weathered and fissured stone is rejected, although some part of it may be used for road-metal or rough walling, etc. To the output for sandstone some 50% may be added to include waste stone, in addition to any overburden. In the case of limestone much stone unfit for building would be used for road-metal or burnt into lime, and therefore is not waste. In granite quarries the chippings are now not infrequently utilised for road-metal and artificial flagstones, while in the case of other igneous rocks it is chiefly for road-metal that they are being quarried. In the case of slate one ton of output means on the average 15 tons of rock excavated. Gravel not infrequently con-

tains clayey patches which are worthless. These are left intact when possible, so that a gravel-pit often shows pinnacles ("heads") standing up sporadically over the floor. Almost always there is soil and subsoil to be removed before any valuable materials can be obtained. This naturally forms a bigger proportion of the excavation in the shallower quarries. We may now make a new table showing the number of cubic yards of output, the percentage allowed for waste, and the volume of the excavation, allowing for waste.

	Output 1895-1913 in cubic yards	% allowed for waste	Volume of excavation in cub. yds.
Gravel	29,382,000	20	35,258,000
Clay (quarried)	143,718,000	15	165,276,000
Sandstone (quarried)	55,755,000	60	89,208,000
Igneous Rocks	46,619,000	15	53,602,000
Limestone (other than chalk)	113,268,000	15	130,258,000
Chalk	43,135,000	15	49,605,000
Chert and Flint	771,000	15	887,000
Gypsum (quarried)	436,000	400	2,180,000
Celestine	97,000	600	679,000
Slate (quarried)	3,278,000	1,400	49,170,000
Iron-stone (quarried)	30,370,000	90	57,703,000
		Total	638,826,000

In addition we must allow, from quarries not exceeding 20 feet deep, an output of sand, gravel, and clay at least equal to that obtained from quarries over 20 feet deep; i.e., including waste, 200,534,000 cubic yards. Including other rocks we may estimate the total from shallow pits at half that from pits over 20 feet deep.

The grand total of materials quarried in the nineteen years, 1895-1913 is then about 958,239,000 cubic yards.

In 1895, the first year after the Act came into force, the number of quarries inspected was as follows:

England	6,504
Scotland	1,072
Ireland	531
Isle of Man	43
Total	8,150

In 1913, the last year before the war, the figures were:

England	6,129
Scotland	1,443
Ireland	1,130
Isle of Man	51
Total	8,783

The difference in the numbers for the United Kingdom is not great, the mean being 8,451 quarries. The figure includes a few (27 in 1913) open-workings for iron-stone not under the Quarries Act.

Many shallow quarries that escape inspection have much larger outputs than some of the inspected quarries, for gravel, clay, or limestone pits often cover several acres without exceeding 20 feet in depth.

We cannot, unfortunately, find the volume of the average quarry by dividing the total output by the number of quarries, because we do not know the average life of a quarry. I have therefore adopted the following method.

After asking a number of experienced geologists to give their ideas of an "average" quarry, and taking a mean of the replies, which were not greatly divergent, the result is that the size of the average quarry is that of a horseshoe-shaped hollow 100 yards wide (from side to side), 80 yards long (from front to

back), and 26 feet deep all round. Of course a quarry is usually considerably deeper at the back than at the entrance, where, in fact, it is frequently level with the approach-road, and 26 feet is the average depth. The volume excavated from such a quarry is approximately 54,500 cubic yards.

The total output of the inspected quarries divided by the number of years (nineteen) referred to, and divided also by the number of quarries inspected, gives the annual output of the average quarry over 20 feet deep. This annual average output, including waste, is found to be 3,915 cubic yards. This figure may not be far from that of the average quarry not exceeding 20 feet deep for, as already mentioned, these pits are often large though shallow, and collectively they yield quite half as much material as the inspected quarries do, and perhaps much more.

As to the length of life of a quarry, some have a history which extends over several centuries; e.g., Delabole, which was worked for slate in the reign of Queen Elizabeth; and Ancaster, Lincolnshire, which was worked for limestone, probably in Roman times. Others, of great size, were excavated rapidly for a single engineering structure and then disused; e.g., the Holyhead quarries, opened to provide stone for the breakwater. After 7 million tons of rubble and solid stone for the breakwater had been dug they were disused, leaving an excavation estimated from Dr Greenly's maps at about 2,650,000 cubic yards. The quarry is 750 yards long, 180 yards wide, and with an average depth of 50 feet. There is an upper terrace 300 yards long, 160 yards wide, and 25 feet deep. Quarries are often used for brief intervals over a great length of time. Such are some estate quarries, occasionally worked to provide stone for repairs to buildings on an estate.

From the table on p. 74 we find that the output represents about 1·36 of the amount of rock excavated

when waste is reckoned in; therefore the average annual output being 4,146 cubic yards, the amount excavated from the average quarry is 5,637 cubic yards, which, divided into the average volume of a quarry, gives an average " life " of 9·6 years.

We will now try to get an idea of the total quantity excavated from quarries in Great Britain since the earliest times. The total volume of the inspected quarries is obtained by multiplying the average annual output, including waste, by 9·6, the average life of a quarry. The proportion of the quarries inspected in Great Britain being ·8962 of the number in the United Kingdom (mean of figures for 1895 and 1913), that fraction of the total excavation may be assumed to belong to Great Britain. The volume excavated from existing quarries over 20 feet deep is therefore, in this manner, found to be 326,293,000 cubic yards. To this we may add 50% as the volume of quarries not exceeding 20 feet in depth, giving a total of 489,439,000 cubic yards. On p. 72 we found that the excavation from disused quarries in England and Wales was about 11,360,000,000 cubic yards. If the same ratio of 194,744 cubic yards per square mile held for Scotland as for England the excavation from old quarries and pits in Great Britain would be 17,263,861,000 cubic yards, but probably there has been much less excavation in Scotland than in England, as the former is comparatively thinly populated. We shall therefore assume that the total excavation for Great Britain from old quarries and pits is about 15,000,000,000 cubic yards. To this must be added the amount from modern quarries, making a total of 15,489,439,000, or in round numbers 15,500,000,000 cubic yards. Spread uniformly over England and Wales this would form a layer 3·1 inches thick.

Railways.—In the construction of railways it is usual to lay them along the river valleys, or other

plains, as much as possible, so that, with moderate gradients, cuttings and embankments will be reduced to the minimum. At times, however, it is necessary, or profitable, to cross a range of hills or a valley, and this involves digging or embanking. A skilful engineer so aligns his railways that the material excavated in cuttings and tunnels is just enough to make the embankments. As cuttings and tunnels are required in places that rise above the mean level of the ground and embankments in places that fall below, it follows that the material excavated is dumped at a lower level than that at which it occurred naturally, and therefore the general effect is to lower the general level of the country. The bulk of material excavated is lowered by an amount equal to the height above rail level of the centre of gravity of the excavated mass, added to the depth of the centre of gravity of the embankment below rail-level. In the figure the lowering is the sum of the heights AB and CD. If, as is usual, the embankments and cuttings have approximately the same width at rail-level, then, since the amount dug out equals the amount deposited, if the slope of the sides of the cuttings and embankments are nearly the same, the heights AB and CD become equal. This would apply where cuttings are in soft materials well cut back from the rails. However, in rock-cuttings and tunnels, where the sides are nearly or quite vertical, AB would be considerably longer than CD.

On the Great Central Railway the foundation-width of cuttings is 28 feet, and of embankments 31 feet. If all materials excavated go into the embankments, these must be shorter than the cuttings. However, a short embankment would have its centre of gravity at the same level as a longer, but narrow, embankment of the same altitude, and the height CD will not be affected.

Rock excavated is of course broken into fragments

in the extraction, and therefore in the embankments will occupy more space than did the rock in its original condition. The sides of the cuttings, tunnels, and embankments offer new surfaces to natural agents of denudation.

The total length of railways in the United Kingdom, at the end of 1909, was 23,272 miles. In these figures single, double, and multiple tracks are added together, and the considerable length of rails laid down in goods-sidings is ignored. The figures for 1906 have been expanded by Mr E. A. Pratt, who finds that of the 23,063 miles of railway, 12,934 miles had a double track; 1,363 miles had three; 1,091 miles had four; 186 miles had five; 111 miles had six; 47 miles had seven; 29 miles had eight; 17 miles had nine; 10 miles had ten; 6 miles had eleven; 4 miles had twelve; 3 miles had thirteen; and there was 1 mile each with fourteen to nineteen tracks. By difference, the railway mileage with single track was 7,256 miles, and the total mileage of track was 38,872. In addition there were 14,032 miles of sidings, giving a total track, including sidings, of 52,902 miles. The average number of tracks is therefore 2·29.

In estimating the quantity of materials moved during the construction of railways, we ought to know how many tracks were laid; but as this information is not known after 1906 the next best thing is to regard the whole of the mileage given in the official statistics as double track, for single and multiple tracks are much less common than double, and the errors they introduce tend to neutralise one another.

The formation of the Great Central Railway, the latest of the main lines to be constructed in this country, offers an opportunity for estimating the quantity of materials removed or used up, when a railway is built.

Messrs F. W. Bidder and F. D. Fox have given the quantities for the northern and southern sections

of the railway respectively. Combined, they relate to the 106 miles 14 chains of line terminating southwards at Quainton Road, in Buckinghamshire, 43 miles from the London terminus. The earth and rock excavated amounted to 13,821,000 cubic yards; and there were used, of concrete 217,000 cubic yards, brickwork 638,000 cubic yards, ashlar 9,000 cubic yards, ballast 1,120,000 cubic yards, earthernware pipes 365,000 lineal yards. About 15 acres of land are required for each mile of railway. On the northern section there were 522,841 cubic yards of earthwork foundations. Corresponding figures are not given for the southern section, and it is here assumed that they have been included with the "earthwork excavation." The total given here is inclusive of earthwork foundations.

The Great Central line is sufficiently long to pass through varied country and to contain all the "works," as they are called (tunnels, bridges, etc.), usually found on a railway. It may be used therefore to supply the data of an average British railway; and by multiplying the total length of railways in the country by the quantities per mile length, as obtained from the above figures, we find the approximate quantities of materials that have been dug out in making British railways. The quantities of concrete, brick, etc., used up will be given later (see p. 227).

The Great Central figures include sidings and parts, if any, with single or multiple tracks as part of the railway. The estimate of quantities here made is therefore based on the mileage of railway in the United Kingdom, regardless of the number of tracks and sidings. We have seen above that the number of tracks averages two. Dividing, then, the totals given for the 106·175 miles of Great Central Railway by the mileage, we get the figure 130,219 cubic yards as the average amount excavated per mile. On these figures Man had excavated on the British railways, up to 1909,

the enormous amount of 3,030,456,000 cubic yards,[1] which is approximately equal to excavating 1,000 square miles to the depth of one yard.

As illustrations of the scale of individual "works" we may give the following instances on the Great Central Railway, taken from Messrs Bidder and Fox's papers. Victoria Station, Nottingham, has been excavated in Bunter Pebble Beds, except at the southern end where some "made ground" has been removed. The station covers 12¾ acres, it is ⅜ mile long, and 390 feet wide at its widest part. The solid rock cutting is from 24 to 58 feet deep, and the total amount excavated is nearly 600,000 cubic yards. The longest cutting on the railway is to the south of Rugby and is 1¾ miles long, requiring the removal of nearly 1,400,000 cubic yards of Lias clay containing pockets of gravel and silt. From Catesby Tunnel, 3,000 yards long, about 290,000 cubic yards of Lias was excavated and 30 million bricks built in. The embankment at Whetstone, north of Dunston Bassett, contains 850,000 cubic yards.

Messrs G. A. Hobson and E. Wragge record that the Neasden sidings, on the same railway, near London, occupy low-lying land that has been raised over an area 1,700 yards long and 200 yards wide by the deposition of 540,000 cubic yards of surplus materials excavated from the London terminus.

Samuel Smiles mentions that the Tring cutting, on the London and North-Western Railway, yielded 1½ million cubic yards, mainly of chalk. As the number of tracks has since been doubled, probably 2½ million cubic yards have now been dug out and deposited, for the most part, in embankments in front of the Chiltern Hills.

Canals.—The earliest British canal was made at

[1] An estimate in the *London Quarterly Review* for January, 1858, gave the earth excavated during the construction of English railways, up to that date, as 150 million cubic yards.

Exeter in 1563. It was 9,360 feet long, 3 deep and 16 wide, with two locks, and was in all essentials similar to a modern canal. The Sankey Canal, from St Helens to the Mersey, was the next to be made, and was constructed alongside the Sankey Brook. The first canal to be made across country, independently of the course of the existing streams, was the Duke of Bridgewater's Canal from Worsley to Manchester, in 1761. By the end of the eighteenth century most of the British canals had been made, and the system was completed by 1830, with the exception of the Manchester Ship Canal and a few short cuts or arms. Since then the mileage has diminished, for several canals have been converted into railways or become derelict. In 1909 there were in England and Wales 1,927 miles of canals. It has been pointed out by L. F. Vernon-Harcourt that " Owing to the necessity of constructing canals for navigation in a series of level reaches, and the excavation of a trench for the waterway, the earthwork required for making a canal is considerably greater than for a railway of similar length, especially in the case of ship-canals, where it is expedient to introduce as few locks as possible." The material excavated is usually thrown up as banks alongside the canal.

English canals are usually from 40 to 45 feet wide at the water-surface and 25 feet at the bottom, and the water is, on the average, 5 feet in depth. These figures give a cross section of about 178 square feet to be excavated on level stretches. There are also cuttings, some of them deep, e.g., on the Shrewsbury Canal, near Brewood, a few miles north of Wolverhampton; on the other hand there are places where the canal runs along an embankment. This latter case is sometimes due to subsidence of the ground having taken place: in such cases the canal may have been originally made on the surface-level, or even in a cutting, as in several cases in South Staffordshire.

There are no data obtainable for the amount of material excavated from cuttings, but in the case of canal-tunnels, of which the total length in England and Wales is 58,743 yards (Scotland has one tunnel only, 696 yards long and Ireland has none), I have estimated that the average cross-section is 200 square feet, and therefore that the total excavation from canal-tunnels in England and Wales is 1,305,400 cubic yards.

Deducting the 33 miles of tunnels from the total length of canals (1,927 miles), and ignoring cuttings, we find that with an average cross section of 178 square feet, as estimated above, the volume excavated is 197,784,106 cubic yards. Adding the amount dug out of tunnels, and remembering that cuttings have been omitted, we may safely put the amount excavated from canals in England and Wales at over 200,000,000 cubic yards, not reckoning the figures for the Manchester Ship Canal. This canal deserves separate treatment on account of its dimensions. At Runcorn, the cutting is not less than 70 feet deep, and for the next 6 miles is from 35 to 60 feet in depth. The minimum bottom width is 120 feet, and the length is $35\frac{1}{2}$ miles. The total amount excavated was $53\frac{1}{2}$ million cubic yards, of which 2 million were sandstone rock and the remainder loose material. Part of the rock and earth excavated was utilised to fill in the river-channels where these had been diverted into the canal; but the greater part was deposited in spoil heaps and railway-embankments. Five railways cross the canal and the original lines were raised by long embankments, giving a gradient of 1 in 135 on both sides and high enough to give a clear headway for ships of not less than 75 feet at ordinary tides. The Manchester and Salford Docks cover 104 acres, have 152 acres of quays, and contain 30 miles of railway-lines.

Road-cuttings.—These are in part the result of

attrition by traffic, but to a great extent are due to direct excavation by engineers. Some instances of attrition are given in the next chapter (p. 121); here we are only concerned with the quantity of material excavated.

Near towns situated in hilly regions it is usual to find roads cut as notches into steep hillsides. Often, too, houses are built on ledges dug out of solid rock. A few amongst many instances are Sheffield, Barmouth, and Todmorden, where in each case the rock is usually a massive grit. In such places road-excavation reaches impressive proportions, and it is difficult to strike an average between such cases and the plains, where road-cuttings are practically absent. The fact that it is usually hard rocks that need to be cut into adds of course to the geological importance of road-cuttings, since such rocks are the most resistant to natural erosion.

Some road-cuttings represent an amount of denudation comparable with that produced by an extensive railway-cutting. An instance is the new road at Welwyn, Hertfordshire, leading from the village to the station. The cuttings are in gravel and are 790 yards long and 30 feet in average depth, while the bulk excavated is about 94,800 cubic yards. Another instance is the Derwent gorge at Matlock which is so narrow that it had to be enlarged by blasting to make room for the turnpike road.

In the more mountainous counties the cuttings are often in hard rocks fit for road metal. No attempt can be made to estimate the total quantity of road material excavated in this manner. The materials, added to those picked off the fields, obtained from loose boulders, the sea-shore, and damaged monumental and building-stones, and also from slag, will go a great way towards accounting for the discrepancy between the estimates of stone annually worn away on roads and that quarried for road-pavements (p. 116).

An estimate of the bulk of rock and soil excavated in roads is even more difficult than in the case of quarrying. However, the area of 3 square miles shown on the western half of Ordnance Survey six-inch map, Hertfordshire 21 S.E., was examined, and the loss of material from road-cuttings was found to be 52,269 cubic yards. Of this, 26,750 cubic yards came from one extensive cutting on the high-road from Ware to Watton. The average excavation per square mile would be 17,423 cubic yards, but the area seems to be rather more hilly than the average of the country, and consequently the average per square mile for the whole country will be taken at only half the amount, say 8,500 cubic yards per square mile. In the case of Scotland the figure will be again halved on account of the great area of almost uninhabited land in the Highlands. The estimate therefore of the total excavation from road-cuttings in Great Britain is 624,144,500 cubic yards, or in round figures 624 millions. This estimate is of course based on a small amount of data, but it does not seem likely to prove excessive, as it is only about one-fifth of the estimate for railway excavations.

Docks and Harbours.—In many cases large quantities of rock have been excavated during the making of docks. Instances are given in the chapter on Alterations of the Sea Coast (p. 252), but no reliable estimate of the total excavation can be made, for the necessary data are known in only a few cases. However, 100 million cubic yards of excavation seems a moderate allowance from this source for Great Britain.

Foundations of Buildings and Street Excavations.—A very large amount of rock and soil must be excavated in digging out the foundations of buildings and in various street excavations, whether to lay drains, gas or water pipes, telephone or telegraph wires. Until recent years the excavations have usually been

shallow, and not, as a rule, carried below the sub-soil. Of late years more lofty buildings are being built and foundations are consequently being dug more deeply; also the large cities are excavating solid rock in their main drainage schemes. In the case of London we have figures for the main sewers (p. 166), but similar data have not been obtained for other cities and towns. The excavations for the main and storm water sewers of London alone amount to 14 million cubic yards, and the total for all the excavations covered by the present section must be several hundreds of millions of cubic yards.

Total Excavation in Great Britain.—We must now add up the various kinds of excavation discussed in the preceding pages.

Total Excavation in Great Britain.	Cubic yards.
Mines	19,692,000,000
Quarries and Pits	15,500,000,000
Railways	3,030,456,000
The Manchester Ship Canal	53,500,000
Other Canals	200,000,000
Road-Cuttings, about	624,000,000
Docks and Harbours, say	100,000,000
Foundations of Buildings and Street Excavation, say	500,000,000
About	39,709,000,000

This total, while it does not pretend to a high degree of accuracy, is nevertheless probably sufficiently accurate to give a just idea of the amount of excavation in this country. We shall discuss its significance in the final chapter.

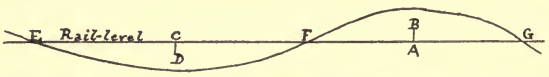


Diagram to show how the construction of a railway causes the transport of rock to lower levels.

CHAPTER III

DENUDATION: ATTRITION

Roads.—One of the greatest changes in the earth's surface wrought by man is due to the way in which he has covered many square miles of it with pavements and buildings. These act as armour, protecting the ground against the ordinary agents of denudation. Although such surfaces are themselves exposed to atmospheric agents, they have been expressly chosen for their high resistance to denudation, and moreover, should they yield to attack they are promptly repaired and the ground underneath remains unaltered. On the other hand, pavements are subject to a special kind of denudation, that of constant attrition. Perhaps the natural agent nearest in character to the wear of traffic is the action of certain glaciers on their rocky beds. In both cases there is attrition of unweathered rock, whereas denudation almost always acts on weathered rocks. This difference between artificial and natural denudation is dealt with elsewhere (see p. 329).

The amount of denudation due to the wearing away of metalled roads by traffic is very great. It may be estimated by the quantity of materials required in a given period to keep the roads in good condition, or by observations on the " life " of roads of different kinds. Some roads require re-making more frequently than others, though the worn materials taken up may be used again in a less important place. But if a suitable area and period are considered, the quantities of new materials used to keep the roads in repair will be the

measure of the quantities that have been ground to powder and have found their way either into the drains and thence into the rivers, or else have been blown in the form of dust on to the land and become part of the soil.

The alternative method of estimating the amount of denudation is to find the output of all the quarries engaged in producing road-metal, setts, paving-stones and "hoggin," corrections being made for artificial materials such as slag, bricks and tiles, and also wood, which are now being used in large quantities. These artificial materials (except wood) have themselves come from quarries, for they are the ultimate products of coal, iron-stone, clay, limestone and so forth. These substances, however, are for the most part soft, when dug out of the earth, and may be considered separately from the hard rocks quarried for covering roads or streets.

In trying to estimate the bulk of rock excavated in Great Britain for pavements, and worn away, since the earliest times, there are naturally great difficulties to be met. The amount used per annum has increased very rapidly, partly because of the increase in population and traffic, and partly on account of the improvement of roads. The coming of fast mail-coaches towards the end of the eighteenth century, and the introduction of rubber-tyred vehicles near the close of the nineteenth, had important results on the condition of the roads.

Before the Roman invasion there were scarcely any made roads in Britain at all, only tracks beaten by the feet of men and animals. In the valleys the forests and bogs were well-nigh impenetrable. One forest stretched from the Thames to the Fenland, and is now reduced to Epping Forest; another spread down from West Yorkshire to Nottingham. The Fenlands covered twice the area they do now, and were at that time impassable bogs. These conditions persisted to

a great extent through the Middle Ages, although in certain counties the average of arable land was greater then than to-day. Extreme cases are Somerset, where in 1086 there were 577,000 acres of arable land against 178,967 acres in 1907, and Gloucestershire, where there were 589,000 against 238,456 acres in 1907. Between the eleventh and sixteenth centuries much of the arable land was laid down to grass, but a great deal of the country was in a wild and uncultivated state. Woods sometimes grew right up to the walls of towns. An unbroken series of woods and fens stretched right across England from Lincoln to the Mersey and from the Mersey to the Solway and Tweed.

Before the country was settled natural ways of communication were offered by the grass lands, and the chief of these were the chalk downs. A track, which afterwards became the Pilgrim's Way, was beaten out by bare feet along the southern outcrop of the chalk, and, similarly, the Icknield Way was formed along the top of the Chiltern Hills. "Ridgeway" roads, however, are not confined to the chalk areas, but are found in many parts of the country. In the Brendon Hills, Somerset, for example, a road extends along the top of the ridge in a nearly straight line for many miles and is associated with numerous tumuli, indicating its great antiquity.

The Romans were the first European nation to attain an advanced stage in highway construction. In the prosperous days of the Empire, 29 military roads are said to have radiated from Rome and these with their branches had a total length of more than 50,000 miles. The roads were from 8 to 16 feet wide, and the paving materials were 3 or more feet in thickness. First of all the engineers dug a trench the entire length and width of the roadway, and in this placed the road-materials in four layers, as follows: (1) At the bottom was laid the *statumen*, consisting of two courses of large flat stones laid in lime mortar. (2) Next came

the *rudus*: broken stones mixed with one-third the quantity of lime, and well consolidated by ramming. (3) The *nucleus*, above, was a mixture of broken bricks, potsherds, tiles and lime. (4) On top of all came the *summa crusta*, a pavement of irregular shaped stones, about 6 inches thick, closely jointed and fitting together with great accuracy. In time the layers became compact and formed a solid mass almost as durable as solid rock. This general plan of road-making was modified to suit local conditions. A piece of the Fosse Way near Radstock, Somerset, was found to have the *statumen* of rubble-stones without lime, 5 inches deep at the centre, and with its base at natural ground-level. The *rudus* was 15 inches thick; the *nucleus*, 10½ inches of fine powdered material mixed with lime and well rammed; and the *summa dorsum* of paving-stones, 4 or 5 inches thick, and firmly cemented. "Thus was formed a ridge well above the surrounding surface, a sort of raised back-bone, high and dry, compact. The edge of each layer is thinner than the centre so that the street was rounded, and grooves were usually cut to help the wheeled traffic."

The old Watling Street at Rochester, below the High Street, shows the extent to which the composition of a Roman road varied from the normal. Here was found, in downward succession, first 7 feet of earth and debris covered by the modern pavement, then (1) angular gravel 14 inches; (2) flints, laid in, six inches; (3) angular gravel, rammed in, 12 inches; (4) chalk, rammed in, 6 inches; (5) a bed of sand, earth and flints, 15 inches thick.

When the road had to cross marshy ground to reach a ford or negotiate a fen, the Romans laid down piles of timber or brushwood as a foundation. The causeway westwards from the bed of the Medway opposite Rochester to the foot of Strood Hill was composed (from below upwards) of:

1. Marsh mud containing curious worked piles, about 4 feet in length, with pieces of wood laid at intervals above them, and perhaps finally made fast with nails.
2. Flints, whole and rather large, rough pieces of Kentish rag and broken Roman tiles, 42 inches.
3. Rammed chalk, 5 inches.
4. Flints broken fine, 7 inches.
5. Small pebble gravel mixed with black earth, rammed, 9 inches.
6. Paved surface of the causeway, Kentish rag boulders cut polygonally, the interstices having been filled in with very fine pebbly gravel, 6 to 8 inches thick.
7. Layers of post-Roman road, 32 inches.

The approximate width of the causeway was 14 feet, and grooves were cut or worn in the pavement. Earth was turned up in two parallel ditches, on either side of the road.

The materials available for road-making naturally varied locally; the chalk and flints, for example, used in the road at Rochester would be obtained from the chalk outcrop. The stones used were most probably boulders or blocks gathered from the surface, or obtained by shallow digging, as a rule, but occasionally paving-stones were quarried. Very little is known about Roman road-making in this country. Codrington's " Roman Roads in Britain " has been used for the following information. He writes:

" An embankment is a very usual feature, and constructed with the utmost care on a solid foundation with suitable materials, it constitutes the ridge of the road, which often remains almost unchanged by time when man has not disturbed it. . . . The height of the embankment or ridge was sometimes considerable, not only where a low place had to be crossed, but on high

ground. Perhaps the most striking example remaining is the embankment called Atchling Ditch or Dyke to the south-west of Salisbury, which for four miles runs across the high open down almost unchanged in profile, 5 yards across the top and 5 or 6 feet high. . . . In some places the Roman road has been removed for the sake of the materials, so that instead of a ridge, a wide shallow trench remains. In other places the paved foundation is found a foot or more below the level of the ground without a trace of the road on the surface. This has arisen from the removal of the upper part in the interests of cultivation, the portion beyond the reach of the plough having been left; deeper ploughing has caused this process to be repeated in recent years. It is, however, difficult to suppose that the roads were in all cases raised. . . . The width of the embankment appears to have varied from 6 or 7 feet, as at Radstock, to 6 or 7 yards south of Jackments Bottom, both of these places being on the Fosse Way. Deep trenches were commonly dug on the sides of the road, the materials from which, when suitable, went to raise the ridge, but in soft places it appears to have been cast outwards. . . . Where Roman roads have been modernised the side ditches have become the natural receptacles of mud, etc., from the road surface, with which they are filled up.

" Perhaps in this country the surface of the roads was more generally made of gravel or stone, grouted with lime or coarse mortar, and of a considerable thickness. Camden describes roads which in his time were of gravel, as in the case of Kind Street between Middlewich and Northwich, made of gravel brought from a distance. The Sussex Stane Street when it was cut through early in the century, in a situation where previous disturbance was unlikely, was found to consist of ' $4\frac{1}{2}$ feet thick of flints and other stones laid alternately and bedded in sand or fine gravel.' The

Roman road near Woodgates, between old Sarum and Dorchester, appears to have been of gravel. The ridge on the chalk down is as much as 6 and 7 feet high, and when it is away from a modern road appears to be in its original state. Where it has been cut through for a drove-way, a coating of tertiary gravel $2\frac{1}{2}$ to 3 feet thick is exposed that must have been brought 4 or 5 miles, and any material for a paving was probably not to be got. Evidence of the same sort is to be seen for several miles farther on.

"The surface was certainly sometimes paved. Camden describes the Kentish Stane Street as being paved with stone. Stukely found part of Erming Street north of Huntingdon still paved, and describes the paving of the Fosse Road south of Ilchester as consisting of the flat quarry-stone of the country, of a good breadth, laid edgeways, and so close that it looked like the side of a wall fallen down, and the road remained much in its original state up to the beginning of the last century. . . . Stukely . . . described Leeming Lane on Erming Street as paved with large coggles which were being taken away for buildings, and which are still to be seen in adjacent walls and buildings."

With the passing of the Roman power the roads were neglected. The Angles and Saxons preferred to build their villages on streams, away from the roads. New tracks were trodden out between the villages, but there was practically no traffic along the old roads, and these became derelict. Mr Hilaire Belloc, in "The Stane Street," explains the decay of the Roman roads after the twelfth century in the following manner. As the population of the Saxon villages grew, the devious tracks between them became hardened, and, first rivalling, later supplanted the Roman roads. Again, the cost of upkeep of the roads where they were expensively engineered led to their neglect. This is particularly the case in mountainous districts, over

morasses, or where the road had to make use of great bridges. But cuttings, though expensive to make, maintain themselves. Thirdly, there were new political relations between one centre and another. For instance, when Windsor became a place of government it needed a road to London, and only part of the way was served by the old Roman road to Staines. Fourthly, the growth of forests. In the Middle Ages woodland once arisen was preserved, because the people burnt only wood and it was also the chief material of construction; moreover, it afforded hunting and was the pasture of the swine. In many cases gaps in the Roman roads are due to woods having overgrown them, e.g., the Nore Wood on the Stane Street covers two miles through which the road has completely fallen into disuse. Very old trees, even, grow upon it throughout this stretch. By the time that the woods which arose in the Dark Ages began to be cleared again, the use of the road had disappeared. Fifthly, many of the roads were purely strategic, and when their strategic purpose disappeared their continuous use throughout their length also disappeared. Sixthly, the paving or metalling of certain new roads alternative to Roman roads caused traffic to follow the hard way and the old road ceased to be used. Finally, the growth of trees tends to reduce the roads to local by-ways or to obliterate them, and the coming of railways has also caused them to lose traffic.

Mr Belloc writes: "It was customary throughout England to leave a wide space upon either side of any old Roman way, in order to provide alternative tracks for the heavy wagons which cut up the soil in wet weather, and especially upon clay. When the left hand side of such a belt has been turned into a morass by the frequent passage over it, it was given a rest and traffic went to the right."

Where the ground was damp and soft the traffic followed a circuitous course until it rejoined a sound

part of the old road. The bad parts tended to disappear under the plough.

Again to quote Mr Belloc: "Society sank into a number of self-contained and self-sufficient countrysides. To get from the chief market of these to the various villages was a necessity; but only along the very largest arteries of European travel (such as the Watling Street) was it still necessary, after the breakdown of the Central Government, to proceed continuously and in large numbers from, say, London to a port, or from one bishopric to the next."

The falling in of a culvert might cause water to rise against the causeway of the road and produce a worse swamp than before, causing the road to be deserted. Where a Roman road crosses marshy ground it is almost always lost. "The weight of the structure has gradually sunk into the soft soil, and in the absence of repairs it has at last been engulfed."

"Secondly, a Roman road being, as a rule, raised above the surrounding country by a few feet, it was, as we have seen, exceedingly inconvenient to travel along it, wherever its surface had fallen out of repair. Traffic, therefore, would take to the belt upon either side of such a break, and this accounts for the fact already mentioned that along all the Roman roads of Britain and Gaul the actual narrow line of the original way is often found skirting the modern road just to the right or to the left of it. . . . When metalling was undertaken in modern times, when many of the roadside spaces were simultaneously enclosed, the hard surface would follow a narrow strip corresponding to the most used and beaten part of that belt." Hence a modern lane or road often follows a Roman road closely and uses it as a bank, which is often surmounted by a hedge and forms its boundary.

From the time of the Roman evacuation of Britain practically no road-making was done in the country until the middle of the eighteenth century. The roads, as

we have seen, were originally mere footpaths or horse-tracks, and the few wheeled carriages were of rude construction, for which roads were wholly unadapted. They were tortuous, any obstacle turning the traveller aside. Many went over hills to avoid marshes, others deviated to communicate with fords of rivers, now passable by bridges. Inland commerce was carried on chiefly by pack-horses. In Norman and early Plantagenet times there was a considerable amount of travelling. Nobles migrated from one manor to another, the policy of the Norman kings being to split up their vassals' estates into scattered pieces to prevent rebellion. Hence the nobles with their retinues were constantly moving, and the roads were also busy with miscellaneous traffic, chapmen, pilgrims, etc. (*v.* Jusserand). Moreover, the bishops were constantly in communication with Rome about legal business. However, estates presently became consolidated and the nobles no longer travelled much, while the Wars of the Roses also brought about great changes. The roads became deserted and were allowed to decay.

After a long interval of time the roads gradually became passable for the primitive carriages and were maintained by local taxes on parishes until turnpikes were introduced by law. Several of these were installed before 1765, and subsequently they became general. It was a long time, however, before a good system of road-making was established. Old horse-tracks generally followed, with a few deviations, deep ruts filled with stones or any material at hand. These were thrown on in an irregular mass and roughly spread to make them passable; the best of them would now be intolerable. Engineers, except in the case of exceptional difficulties, such as when it was necessary to bridge a deep or rapid river, to make a cutting through a hill, or an embankment across the valley (very rare occurrences), thought roads beneath their notice; and it was considered singular when, in 1768,

Smeaton condescended to make a road between Markham and Newark-on-Trent.

Before passing on it will be instructive to give some facts illustrating the conditions of British roads before Telford and Macadam introduced modern methods of road-building. They will be given in chronological order, as far as possible, and are derived in part from Smiles' " Lives of the Engineers."

In the reign of Edward III. the footway at the entrance to Temple Bar was interrupted by thickets and bushes, and further west faggots were thrown into the ruts in King's Street, Westminster, when the king went to Parliament. Between 1331 and 1380 Parliament three times adjourned because the state of the roads kept many members from attending.

Mrs J. R. Green, in her " Town Life in the Fifteenth Century," writes (Vol. II, p. 31): " In 1499 a glover from Leighton Buzzard travelled with his wares to Aylesbury for the market before Christmas Day. It happened that an Aylesbury miller, Richard Boose, finding that his mill needed repairs, sent a couple of servants to dig clay, called ' Ramming clay,' for him on the highway, and was in no way dismayed because the digging of the clay made a great pit in the middle of the road 10 feet wide, 8 feet broad, and 8 feet deep, which was quickly filled with water by the winter rains. But the unhappy glover, making his way from the town in the dark, with his horse laden with paniers full of gloves, straightway fell into the pit, and man and horse were drowned. The miller was charged with his death, but was acquitted."

The first Act for paving and improving the City of London was passed in 1532. The streets are described at that time as being " very foul, and full of pits and sloughs, so as to be mighty perilous and noyous, as well for all the king's subjects on horse-back, as on foot with carriages." Before the turnpike system was introduced, the metropolis and other large towns were

paved with rounded boulders, or large irregular pebbles, imported from the sea-coast. Usually they were from 6 to 9 inches deep for the carriage-ways and about 3 inches for footways. Boulder pavements were succeeded by pavements made of blocks of stone, usually of tolerably good quality and from 6 to 8 inches across the top, but so irregular in shape that even the surfaces did not fit. The stones were but lightly hammer-dressed. Often they tapered downwards so that the loose bed became mud and worked up between the stones, which sunk into holes. This method of paving was in existence up to about 1830, when, as the result of Telford's work, modern paving was adopted, and by about 1850 the old style had practically died out.

From statutes of Henry VIII. it appears that in Sussex and the Weald of Kent, when old roads became too deep and miry to be passed, they were abandoned and new tracks struck out, and the Act allows old roads to be closed and new ones laid out. Little was done, however, and in Elizabeth's reign the great western road was so bad that in winter travellers waded through deep mud at Knightsbridge. Farther from London matters were worse. Roads were mostly tracks over heaths and commons, furrowed with ruts like ploughed fields. All the mending done was to throw large stones into the bigger ruts to fill them up. The land being unenclosed, it was usual, when the road got very bad, to make a new track alongside the old one. Beacons were erected to warn travellers of the more dangerous quagmires, and guides were necessary to point out the safest fords, in the absence of bridges. Certain hollow ways still found in parts of England, in some places 8 and 10 feet deep, represent the old roads, which in winter were rivulets. Some in Wiltshire, Somerset, and Devon are as old as, or older than, the Conquest.

So little was known of the more distant parts of

England that in 1607 we find Camden describing Lancashire as that part of the country " lying beyond the mountains towards the Western Ocean." In country places stores were laid in for the winter as if for a siege. Most of the sheep and cattle were killed and salted down at Martinmas, while stockfish and baconed eggs were provided for Lent; for during six months the roads were closed.

Before the formation of the Great North Road it was one of the principal bridle-paths from London to the northern parts of England; but it was so narrow as barely to afford passage for more than a single horseman, and so deep that the rider's head was beneath the level of the ground on either side.

During the Civil War 800 horse were taken prisoners in Buckinghamshire while sticking in the mud. When rain fell, travellers all came to a standstill until the road dried again. In 1645 it took two days to travel from London to Chertsey. One of the first coaches in England was used by Queen Elizabeth; but for a long time roads were barely practicable for wheeled vehicles of the rudest sort. In 1675 Thomas More wrote that much ground " is now spoiled and trampled down in all wide roads, where coaches and carts take liberty to pick and chuse for their best advantages; besides, such sprawling and struggling of coaches and carts utterly confound the road in all wide places, so that it is not only unpleasurable, but extreme perplexin and cumbersome both to themselves and all horse travellers." Stage-coaches were introduced about the middle of the seventeenth century, and probably between London and Dover, as this was one of the best roads at that time. In 1685 the Irish Viceroy could not use his coach much of the way in North Wales, and it had to be borne after him. Between Conway and Beaumaris he was obliged to walk. Carriages were usually taken to pieces at Conway and carried by Welsh peasants to be embarked at the Menai

Straits. To show the extent of travelling, about this time, it is stated that between London and the three principal towns of York, Chester, and Exeter, not fewer than 1,872 persons travel by stage-coach in the year. In 1700 York was a week distant from London; Tunbridge Wells, Salisbury, and Oxford were each two days; Dover three days; Exeter five days. As late as 1763 it was a fortnight's journey from London to Edinburgh, the coach starting once a month.

In 1724 a writer, describing the country between Tunbridge Wells and Lewes, says: "Sometimes I have seen one tree on a carriage, which they here call a *tug*, drawn by two-and-twenty oxen, and even then carried so little a way and then thrown down and left for other tugs to take up and carry on, that sometimes it is two or three years before it gets to Chatham; for if once the rains come on, it stirs no more that year, and sometimes a whole summer is not dry enough to make the roads passable. Here I had a sight which, indeed, I never saw in any other part of England, namely, that going to church at a country village, not far from Lewes, I saw an ancient lady, and a lady of very good quality I assure you, drawn to church in her coach with six oxen; nor was it done in frolic or humour, but mere necessity, the way being so stiff and deep that no horses could go in it."

Arthur Young in "Six Months Tour," published in 1770, says: "To Wigan. Turnpike.— I know not, in the whole range of language, terms sufficiently expressive to describe this infernal road. Let me most seriously caution all travellers who may accidentally purpose to travel this terrible country, to avoid it as they would the devil, for a thousand to one they break their necks or their limbs by overthrows or breakings down. They will here meet with ruts, which I actually measured 4 feet deep, and floating with mud only from a wet summer; what therefore must it be after a winter. The only mending it receives is tumbling some loose

stones, which serve no other purpose than jolting a carriage in the most intolerable manner. These are not merely opinions, but facts; for I actually passed three carts, broken down, in these eighteen miles of execrable memory."

Even as late as 1809 roads answered to Young's description, but the General Views of the Agriculture of the Counties of Great Britain, a series of volumes published about the beginning of the nineteenth century, show that the coming of turnpikes and mail-coaches had caused a great improvement in many counties. Mr John Holt, in his report on Lancashire, dated 1795, one of the earliest of the series, speaks favourably of the roads there. He says that it has a greater proportion of roads for its extent than any other county. To show the "vast length" of the roads, he mentions that the parish of Goosnargh, with an area of 3,703 acres, has nearly 40 miles of roads, besides 3 miles of bridle-roads and 3 miles of roads repaired by certain individuals. Also the township of Walton, now part of Liverpool, containing 1,988 statute acres, had $2\frac{1}{2}$ miles of public and $11\frac{1}{4}$ miles of parochial roads, besides occupation roads. At that time local materials, such as limestone, were used in the northern and eastern parts of the county, but, in the midland and southern parts, the materials, except what was afforded by the rivers, were brought from the Welsh and Scotch coasts. These were "boulder-stones," and were not broken, but laid so as to form a pavement. He mentions that two quarries of pebbles (no doubt Bunter Pebbles) had lately been discovered. Copper-slag from two works at Ravenhead and Liverpool had been tried and was found to make an excellent side road to the pavements. Admirable roads of copper-slag had been made near Warrington. The weight of mail-coaches when loaded was nearly 2 tons, and heavy coaches 3 tons. The effect of four horses scampering and pulling with all their might is said to

have been very injurious to the roads, for after stones had been displaced by their feet, followed by a heavy carriage on four narrow wheels, every obstruction is moved by the violence of the motion.

John Middleton, writing in 1807, in the same series, on Middlesex, says that the parish roads in that county are superior to those of equal extent in any part of the country. They are hard and clean in every weather. One may ride along them even directly after rain and scarcely receive a splash. The turnpike roads, however, were generally very bad. They were kept many inches deep in mire, and the sludge was thrown all over a horseman, even into his eyes, on meeting horses. Of the Edgeware Road he says that, by way of repair, fresh gravel was laid on the top so that the first cart cuts it into ruts and it remains so all the year. The road from Tyburn (Marble Arch now) to Uxbridge had the most traffic in the county and perhaps in the kingdom, yet, in the winter of 1797-8, there was only one possible track on the road, and this was less than 6 feet wide and 8 inches deep in fluid sludge. All the rest of the road was covered by from a foot to 18 inches of adhesive mud. The track was thronged with waggons, many drawn by ten horses and most with broad wheels, even up to 16 inches wide, and with farmer's carts with wheels 6 inches wide. It was with great difficulty that a horseman or light carriage could pass. Nevertheless the author says the roads are much better than fifty years before, hence the safe, cheap, and expeditious travelling in mail-coaches, in which Britain is unequalled. All roads near London were repaired with gravel or flint-stones.

From the volume on Rutland by Richard Parkinson, published in 1808, we find that although, when the Enclosure Acts were passed, strips of land 49 feet wide were reserved for roads, yet, owing to bad engineering, only the middle part, 9 to 10 feet in width, could be used.

Scotland as a whole was far behind England. In 1803 a writer in the Farmers' Magazine sums up his account of the country thus: " Except in a few instances it was little better than a barren waste." With the coming of roads into the Lowlands there was a rapid change there, and from a brown moorland affording support in winter to the hardy black cattle, with small patches of badly cultivated ground containing oats and barley with abundant weeds, the country became a richly cultivated land with now and then a few acres of brown moss left in its primitive state. This change took place in the latter half of the eighteenth century. It was confined to the Lowlands, for at that time the only decent roads were the 800 miles made by Government after the rebellion of 1745. The plough had not reached the Highlands; the people used the caschrom or " crooked foot," which was pushed into the soil to turn it over. The Rev. Mr Macdougall of Argyllshire described the people, in 1760, as so poor that they were often reduced to bleeding their cattle and subsisting on the boiled blood. There was no road of any kind west of the Great Glen, a state of affairs that lasted until Telford began to make his roads, bridges, harbours and canals in 1804. With the introduction of Telford's system of road-making in 1803 and Macadam's in 1816, modern road-making, in England, may be said to have begun.

My reason for spending so much space on the history of roads in Britain is to estimate the period during which the present conditions of road denudation have existed. We find that modern road-making began only in the nineteenth century, and previous to that it was only during the Roman period that there were decent roads in Britain. We may therefore divide the history of British roads into four periods: (1) Before the Roman roads were made; (2) the period of Roman occupation; (3) from the end of the Roman occupation to early in the nineteenth century, when

modern road-making was introduced; (4) from the introduction of modern roads to the present day, approximately a century.

The amount of erosion depends on the time during which the agent acts and on the rate at which it works; hence the necessity for the above divisions, which represent the different periods during which the rate of denudation had different values.

In the first period, before the making of the Roman roads, Man's denuding action was similar to that of other animals. Just as a herd of buffaloes will beat out with hoofs a path to the watering-place, so primitive Man beat out with his feet such roads as the Icknield Way. It is not unlikely that he sometimes threw pieces of rock into swampy places, or into streams, to make stepping-stones, and so performed a primitive engineering feat; but this is not a purely human action, for greater engineering feats are performed by beavers when they dam a stream and make a considerable lake. At this time the population was probably very small, though we have no figures. The human denudation during this period is practically negligible; the limited population did scarcely any travelling from place to place, and used neither vehicles nor iron-shod horses, and such wearing away as was actually affected was performed by Man in his animal rather than in his human character.[1]

In the second period, that of the Roman occupation, distinctly human erosion was effected. Definite strips, the metalled roads, were undergoing abrasion during a period of about 500 years.

The rate at which the roads were abraded is unfortunately not known; it is only in recent times that we have any data to work on.

[1] However, Mr. T. Sheppard states that there were a few roads in existence at the time of the Roman invasion. One of these, a road from York to the Humber, was good enough to be taken over by the Romans.

The Romans used metal studs in their shoes and shod their horses, thereby introducing a new element of abrasion.

In the third period, after the Roman occupation, their roads were partly allowed to wear out without repairing, partly left to become overgrown, partly pulled up in order that the stones they contained might be used for building. Conditions were much as in the pre-Roman period except that (1) the population slowly increased on the whole, though with periods of decrease; (2) traffic, at first almost non-existent, increased as the times became more settled; (3) vehicles began to be used late in the period and introduced a new abrasive element. Shoeing of horses having been introduced by the Romans probably continued throughout the period, and it was also customary to shoe oxen when they were used to do the work now performed by horses.

For this period also we lack data; but it is safe to say that the denudation effected directly by traffic was trivial compared to that performed at the present day. One important difference between the third and fourth periods should be noted. Until the modern methods of Telford and Macadam had taken root, such mending of roads as was done at all consisted in filling up holes with loose stones, and later on cobbles were brought inland from the sea-coast to make the first town-pavements. Two results must have followed: the country became less stony owing to the picking off of loose fragments during so many centuries, and secondly the removal of stones from the coast would assist coastal erosion by the sea (see p. 241).

It is in the fourth period, which is still existing, that the bulk of human erosion has been performed. Probably some 99% of the total rock removed by direct abrasion alone has been effected within the last century.

Fourth or Present Period of Road-making.—

About 1830 London began to be paved with granite setts, of different sizes according to the class of streets, and below the setts a foundation of broken stones, 1 foot in thickness, was placed. Macadam was used in some streets for light traffic. Colonel Haywood, Surveyor to the Commission of Sewers of the County of London, found that a pavement of Aberdeen granite-setts, 6 inches wide and 9 inches deep, lasted from 11 to 31 years, after which nearly all the stone could be used a second time, for a similar period, in places of secondary traffic in the City. In 1840, flints, bedded in concrete, were used on Blackfriars Bridge and lasted 13 years.

By 1850, the change to a modern style of paving, begun in 1830, had been completed. In 1851 there were in the City 51 miles of public roads, estimated to comprise 441,250 square yards of carriage-ways and 328,907 square yards of foot-way, a total of 770,157 square yards of pavement. The duration of the granite-setts with which the main streets of the City were paved between 1845 and 1863 averaged 15 1/7 years. The setts were then taken to the stone-yard to be re-shaped and afterwards laid down in secondary streets. After a time they became greatly worn and rounded and were then broken up for macadam, together with the chips broken off when re-shaping, and finally they became pulverised. A Fleet Street pavement lasted 14 years, after which the setts were used in secondary streets for 29 years. The average double life of a three-inch sett of granite was about 30 to 40 years at this period.

In Liverpool, in 1851, there were 174 miles of carriage-ways and 69 miles of courts and passages; or, carriage-ways 2,243,560 square yards, channels 231,362 square yards, foot-ways 1,048,264, a total of 3,523,186 square yards of pavements. The average width of the carriage-ways was 8·1 yards, and they were covered, as regards two-thirds by boulders, and one-

third by macadam. Of the roads 8% were covered by setts from Penmaenmawr (3 inches wide, 7 inches deep), whose life was estimated at 20 years, and 6% was covered by sand and ashes.

In Manchester the early pavements were boulders from the coasts of Wales, Westmorland and Cumberland, as in the case of Liverpool. The boulders ceased to be imported into the city in 1840; and although considerable areas of boulder-pavements remained in 1876, these were replaced by granite-setts when roads needed repair. On main streets, setts from Carnarvon, Portmadoc, Penmaenmawr, Clee Hills and Newry were used, with Millstone Grit setts on the by-streets. Macadam was replaced by setts. The average life of the setts was, at that time, 14 years, after which the roads needed entirely relaying. The Penmaenmawr setts were found to be almost everlasting; next came, in order, Guernsey, Mt. Sorrel and Aberdeen granite. In 15 years the average vertical wear of setts in main streets was about 2 inches, after which they were relaid in minor streets and lasted another 20 years before they lost another 2 inches vertically. A sett 3 inches wide and 7 inches deep would therefore have lost four-sevenths of its bulk before it was regarded as worn out.

For paving-stones, Yorkshire flags, 3 inches thick, were used, and lasted eighteen years in the main streets and then another fifteen to twenty years in side streets, giving a total life of about thirty-six years (another statement gives nineteen years). In 1840 the area of streets swept in the Manchester district was $5\frac{1}{2}$ million square yards.

In London, there were, according to an estimate made in 1869 by Mr Paget, in the 39 districts and parishes, at least $21\frac{1}{2}$ million square yards of macadam, and within 12 miles of Charing Cross at least 40 million square yards. The surfaces of many London streets had to be renewed several times yearly.

Since these estimates were made towns have grown

very considerably in size, and traffic has increased still more rapidly. On the other hand, improvements have been made in pavements and the use of asphalt and wood has tended to diminish the quantity of stone used, while rubber tyres have greatly reduced abrasion by traffic. The pneumatic tyre has only been in use for about a quarter of a century on bicycles, and motor traffic may be said to have commenced in 1896, when an Act allowed the speed to be increased from four to twelve miles an hour. The coming of pneumatic tyres necessitated the improvement of roads.

In 1884 there were 1,966 miles of streets in London, including 248 miles of private roads. The public streets comprised 573 miles under macadam, granite 280 miles, wood 53 miles, asphalt 13½ miles, flints or gravel 798½ miles. These figures show a great increase on those given for 1869; the wood pavement alone in 1884 covering some 980,000 square yards. The total paved area of public streets, allowing 22 feet width on the average, was 21,193,656 square yards. In 1899 the London street area covered 52 million square yards or 12·0 square yards per inhabitant, and in 1911-2 the length of streets was 2,214½ miles, covering, at 22 feet average width, 28,567,050 square yards.

Some observations were made by the author in order to estimate the fraction of the country covered by pavements. In Buckinghamshire,[1] in an area of exactly 3 square miles, selected as typical rural country without villages or waste lands and without high-roads of the first class, the length of metalled roads was 8 miles. The width of the macadamised strip varies from 6 feet on a by-lane to 18 feet on the more important roads, and on the average may be taken at 10 feet. This gives approximately 47,000 square yards covered by macadam, or 15,666 square yards per square mile.

[1] Area covered by six-inch Ordnance Map, Bucks. 39 NW., W-half.

In another case an area of 27 square miles of agricultural land in Staffordshire,[1] containing several villages but no towns, and including some park land and parts of two important main roads, contained 71 miles of roads, and at an average width of 10 feet for the strip of macadam this gives an area of 15,427 square yards per square mile (leaving out gravelled paths in parks and gardens). The two results are singularly near to one another. The figures show that in the two rural districts observed, almost exactly ½% of the total area is paved with road-metal.

Mr J. W. Smith states that in 1908-9 England and Wales possessed 150,455 miles of roads and Scotland 24,770 miles. Excepting a comparatively few, converted during recent years to bituminous-bound roads, about 95% were of macadam or gravel on the water-bound principle. The other 5% either carry such a heavy traffic as to need granite-setts upon a concrete base, or, to meet urban conditions, are paved with wood or asphalt. The English and Welsh roads are classified as: London (Corporation) 48 miles; Metropolitan Boroughs 2,113 miles; County Councils 17,536 miles; County Boroughs 9,136 miles; Boroughs 6,086 miles; Urban District Councils 13,883 miles; Rural District Councils 101,653 miles. The average width, without pavements, is 18 feet. The area covered by all these roads and streets will therefore be approximately 513 square miles for all England and Wales, not considering pavements. The length of roads and streets with side-pavements is not stated; but assuming that all roads and streets in London (Corporation), the Metropolitan Boroughs, County Boroughs, and Boroughs have side-pavements 5 feet wide on both sides, they will cover an area of approximately 33 square miles. The part of England and Wales under some form of pavement would there-

[1] Area covered by six-inch maps, Staffs., 49 S.E., 50 S.W., 55 N.E., 56 N.W. and W. half of N.E.

fore be 546 square miles, in 1908-9, and it is of course continually increasing with the growth of the towns. The 546 square miles is ·9358% or nearly 1%, of the area of England and Wales.

Probably we can take 1% as approximately correct, for there will be side-walks to many urban district and country roads, and also many private walks and passages, not included in the above estimate. This then is the fraction of England and Wales which is subject to attrition from the feet of Man and his domestic animals and from the wheels of his vehicles. An increasing proportion of the road surface, however, is being covered by wood or asphalt pavements, the former derived from trees, the latter from mineral pitch or from coal and therefore dug out of the earth.

Estimates of the quantity of material worn out by attrition on roads are unsatisfactory. They vary greatly and also refer to markedly different periods and conditions of traffic, so that it does not seem possible as yet to arrive at accurate figures. The following data will, however, give some idea of the amount of attrition carried out on roads.

A cubic yard of stone, broken to the usual size of 2 to $2\frac{1}{4}$ inches cube, contains, according to Mitchell, 11 cubic feet of air spaces. When the stone has been rounded by traffic the air space has diminished to 10 cubic feet, or 37% of the total volume. The stones have been crushed into fragments of all sizes down to the finest sand. In a cubic yard of macadam from The Mall there was found to be 41% mud, sand with pebbles not exceeding 3/16 inch in size 9%, stones from 3/16 to $\frac{1}{2}$ inch 24%, stones from $\frac{1}{2}$ to 1 inch $16\frac{1}{2}$%, stones from 1 to $2\frac{1}{4}$ inches $9\frac{1}{2}$%. Here less than $9\frac{1}{2}$% of the stones escaped abrasion and 41% had been reduced to dust. When we remember that the sample, before removal from the road, had been frequently swept and washed free from mud we see that the figures underestimate the abrasion and Mr Burt is

probably not far from the truth when he estimates that one-third the bulk of the road metal in London is ground to powder before the road surface is broken. The road, however, comes to contain only $5\frac{1}{2}$ to 8 cubic feet of air spaces in the cubic yard, or about half the original amount, owing to the dust produced filling the cavities. The vertical wear in London streets was estimated, at that time (1881), at from 1 to 7 inches per annum.

Mr Francis Wood, in 1912, estimated that, in Fulham, the macadamised roads lost 84 tons per mile, or about 1/5 inch per annum. However, the macadam had only 40% of the traffic of the main streets. The macadamised streets needed repairing every two years. If abrasion is proportional to traffic this would give $\frac{1}{2}$ inch of wear on a macadamised road bearing the full traffic of main streets.

Mr Reg. Ryves, in 1907, mentions that a recent report of the Massachusetts Highway Commission finds the average loss on five roads totalling 31·72 miles and of different kinds, to be 0·92 lbs. per square yard per annum. This on a road 30 feet wide is at the rate of 16,192 lbs., or nearly $7\frac{1}{4}$ tons per mile of road per annum.

Mr H. Fox Hill, formerly Surveyor to the Ware (Herts.) Urban District Council, has kindly supplied the following figures of materials used on the streets and roads of that district. During the five years, 1909-14, they required approximately—macadam ("granite") 2,718 tons; gravel 1,218 cubic yards; curb-stones 1,610 lineal feet; setts 47 tons; paving-stones 2 inches thick 2,461 square yards (=410 cubic yards). The area of the district, according to the 1911 census, is 629 acres and the population 5,842.

Estimates, made in 1876, of the wear on French roads varied from 22 to 390 cubic yards of broken stone per mile per annum, but the average amount was about 78 cubic yards. In 1855, according to Messrs

Greenwell and Elsden, the wear of roads in Cardiff varied from 800 to 1,010 cubic yards per mile, the road-metal being limestone, grit and slag.

On the Glasgow-Carlisle road, which was made with whinstone, the wear was from 60 to 120 cubic yards per mile. In Edinburgh, with roads of granite and whinstone, the wear was from 500 to 600 cubic yards per mile. In London suburbs, the roads, of granite, flint and gravel, lost from 470 to 580 cubic yards per square mile. These figures, however, are not applicable to the present-day conditions. In a mile of road, 12 feet wide, an inch of consolidated stone represents nearly 400 cubic yards, so that the wear of roads, as shown by the figures given above, was often more than an inch and sometimes over two inches per annum. A saving is now effected, as a rule, by " general re-charging " a road when it gets worn instead of applying patchwork repairs. To keep holes filled up as they are formed needs 200 to 600 cubic yards of stone per mile per annum, according to the kind of metal, the width of the road, and the amount of traffic. The mean may be taken as 400 cubic yards per mile per annum denuded from roads throughout Great Britain, leaving out of consideration the footpaths at the sides of the roads and private walks in gardens, etc.

Taking Mr J. W. Smith's figures of 175,225 miles as the total length of paved roads in Great Britain and multiplying this by 400, the number of cubic yards annually required, on the average, per mile to keep the roads in repair, we find that approximately 70 million cubic yards of stone are annually used up in Great Britain, in addition to the materials worn away on footpaths. Another method of calculation, however, gives discordant results (p. 116).

It is important to remember that although roads are denuded they are not allowed to be worn into depressions, as would happen to a natural surface. No sooner is a part of the road-covering destroyed than

more material is brought from a quarry to replace it. Hence, although the roads are the places where rock destruction is effected, the results of denudation are seen in quarries in, it may be, a distant part of the country or even of another country. The natural surface under the pavement is "armour plated," as it were, against denuding agents. As the part of England and Wales covered by pavements of one sort or another is about 1% of the total area (p. 110), and another part is protected by buildings, we see that a considerable section of England and Wales is protected from denuding agents.

Footpaths.—Footpaths are usually paved with flagstones in towns, and the best known stones are those from Yorkshire and Caithness. According to Boulnois, not more than 14 stones should cover 100 square feet. In 1886, out of 138 towns giving returns, 23 used Caithness flags. As regards the life of flags, Boulnois says that Yorkshire flags laid in the Strand, in 1861, were completely worn out in 1884, and that they lost 1/16 inch in thickness for every 9 million people who walked over them. Flags laid in Hackney, in 1857, had lost from $\frac{7}{8}$ to 1 inch by 1883. In Kennington, after twenty-five years wear in main streets, they were relaid in second class streets and after another twenty years were set edgewise to make street-crossings. In Wisbeach, after thirty years wear, they were used, on edges, for street-crossings.

In addition to attrition from traffic, flagstones suffer decay from the weather, which tends to split them into laminæ. For example, C. H. Cooper says that in front of the British Museum, where there is no traffic, the Yorkshire flagstones have been reduced in places by more than an inch. This destruction by weather is nevertheless due to human agency, which has taken them from their natural surroundings and exposed them to the atmosphere.

At present much of the flagstone used, probably

more than half of the whole, is artificial, consisting either of chippings of granite, etc., set in Portland cement, and often treated with soluble glass, or clinker from refuse-destroyers. In some cases they are made of iron-slag, cast into slabs. A variety of substitutes for flagstone are in use, notably bricks. In many districts, for example in the Black Country of South Staffordshire, bricked or tiled footpaths are common. They are however, taking the country as a whole, distinctly subordinate to flagstones. In villages and such country roads as possess footpaths they are usually covered by gravel, with a kerb and channel, although these latter are not infrequently absent. The extensive use of artificial products such as concrete, brick and clinker, greatly diminishes the quantity of natural stone required. This means that quarries of solid stone tend to be replaced, to some extent, by clay-pits and gravel-pits, and also that the waste products of towns and quarries, instead of accumulating on the land, are turned into paving materials, and eventually disappear into dust.

Footpaths are not subject to such heavy attrition as carriage-ways. They are to be found almost universally in towns and villages, but not, as a rule, alongside country roads, except in thirteen counties. The Local Government Board, in 1877, ordered that every new street shall have a carriage-way of not less than 24 feet wide and a footpath on each side not less than one-sixth its width; hence all streets made since 1877 have a footpath at least 4 feet wide on both sides. Data are insufficient to enable us to estimate the amount of denudation on footpaths, although it is an appreciable addition to that on carriage-ways.

Mr C. H. Cooper has estimated the life of various kinds of foot-ways in Wimbledon as follows: Gravels (3 inches in thickness of fine binding gravel of small flints) lasted three years, but was never under a heavy traffic; Yorkshire flagstones, 3 inches thick, lasted

fifteen years; artificial flagstones, 2 inches thick, at least thirty years; Blue Staffordshire bricks, 2 inches thick, twelve years; Buckley bricks, 2 inches thick, fourteen years; tar paving, 3 inches thick, ten years; asphalt (concrete $\frac{3}{4}$ inch, asphalt 3 inches) lasted twelve years. He has also stated elsewhere that the greater part of some York flagstones laid in 1886 and removed in 1894 was worn through, but that concrete slabs, under the same conditions, had worn less than $\frac{1}{8}$ inch in eleven years.

So far we have considered the quantities of stone used up on roads. As a check on these figures we may try to find the amount of stone quarried for road-making. We are mainly dependent on the Home Office Statistics for the figures, and great difficulties arise in using them. The form of the statistics has been repeatedly changed; e.g., from 1895, when the list of quarries over 20 feet deep first appeared, to 1897 figures were given for granite, in 1898 granite included syenite, in 1895 and 1896 separate entries were made for whinstone, basalt, etc., which in 1897 became basalt, diorite, etc. In 1898 the figures for all igneous rocks, other than granite, were combined, and from 1899 onwards granite also was included with the rest under the one heading of "Igneous Rocks." Again, some of the stone was used for buildings, although most was used for road-making. Of late years a large and increasing quantity of stone for roads has been imported from Scandinavia, and has prevented an equivalent amount of quarrying being done in Britain. The further fact that the statistics do not include quarries under 20 feet deep is less important in the present case than in that of clay, sand, and gravel, because quarries in igneous rocks are usually of considerable size and depth. Nevertheless there are many small quarries opened for local use which escape the statistician.

A serious difficulty arises from the wrong use of scientific names for commercial purposes. For instance, the quartzite of Nuneaton is known as granite, and appears to be included in the statistics as igneous rock, although it is of sedimentary origin. Similarly the Carboniferous Limestone of the Mendips is known commercially as "granite."

Some additional figures are obtainable from the "Census of Production" for 1907, issued by the Board of Trade, but these do not agree very well with those issued by the Home Office. The stone quarried in the British Isles in 1913, according to the Home Office, consisted of igneous rocks 7,098,493 tons; sandstone 3,977,303 tons; limestone 12,740,664 tons; total 23,816,460 tons. According to the Census of Production 1,110,000 tons of limestone were used (in 1907) for road-metal, but there are no figures to show how much of the other rocks were used for this purpose. Taking average figures for the densities of stone (igneous rocks 2·9, sandstone 2·2, limestone 2·65), the igneous rocks would have a bulk of about 3,200,000 cubic yards; the sandstone of 2,404,000; the limestone used for road-metal about 557,000 cubic yards. Even if the whole of the igneous rocks and sandstone was used for road-metal, which is not the case, the total amount used in 1913 would be not much more than 6 million cubic yards, as against 70 millions required under the calculation from wear and tear of roads given above (p. 112). Even if we assume that a considerable quantity of gravel, slag, flints, imported stone, and other materials was used, it is clear that these two methods of calculation give discordant results.

This is a case where the known data are insufficient to explain the discrepancy. It is much to be desired that engineers will keep account of the quantities of materials of all kinds used on pavements over a considerable length of time. Fortunately we have

obtained an estimate of the amount of rock excavated (p. 86), although we may be uncertain as to the proportion that is ground to powder.

Of the igneous rocks an unknown fraction, chiefly composed of granite, is used as building-stone or for monumental work, and the rest mainly for road-making. In the case of sandstone the bulk would be used for building-stone, with smaller quantities for monumental work, flagstones, ganister (for silica-bricks), etc. The greater part of that used in paving is for flags, and a comparatively small amount for road-metal. Many "granite" setts are made out of millstone grit, and it is a question under which type of rock they have been entered.

The destination of the limestone is somewhat more definitely known. Leaving chalk out of consideration, the Census of Production divided the 10,993,000 tons of limestone got in 1907 into building-stone 350,000 tons; road-metal 1,110,000 tons; burnt for lime 2,740,000 tons; while the use of the rest is not specified.

The stone burnt for lime is completely destroyed as rock and becomes part of mortar or cement, or is placed on the land, where it combines with acids in the soil or atmosphere. The stone used for buildings has a variable life. We are all familiar with the weathered aspect of stone buildings, especially in towns. Limestone used in country places may last for many centuries, as witness our old churches; but in towns the same stone may perish in a few generations. London is full of instances of this (p. 174). Sandstones, unless they have a calcareous cement, last longer than limestones, but suffer by the action of frost and rain as well as by direct mechanical destruction. Igneous rocks resist weather better on the whole. They also are affected chemically by the town atmosphere, which attacks the felspar constituent and so disintegrates the stone. Since it was Man who dug

the stones from places where they were protected from the weather and exposed them to destructive agents, the weathering may be ascribed to human agency.

Sir A. Geikie, after studying the state of preservation of dates on various tombstones, gave some interesting figures of the rate of denudation of monumental stones, the most permanent stone being a good slate. The data could be applied to the stones in buildings which are subject to similar action by the weather.

Buildings are usually pulled down long before the stones of which they are composed are destroyed. A building whose lease has fallen in, or which has become disused, is generally pulled down. The sound materials may be used in other buildings, but there is always a lot of stone not worth using again, or which has been accidentally chipped, perhaps in freeing it from adhering cement. Such damaged stones are generally used sooner or later for "hard-core" for road-foundations, made into concrete, or broken up for road-metal. For a while the stones may lie about on waste land, and some may be incorporated with "made ground"; but sooner or later building-stone, in general, becomes road-metal, and so also does much monumental stone. Thus the greater part of the output of the quarries is eventually reduced to powder, if not totally destroyed.

Details of the output at Mount Sorrel quarry, Leicestershire, will serve to give an idea of what becomes of the rock quarried for road-pavements. In 1900 Mount Sorrel worked 202,000 tons of stone. The output consisted of setts 19,189 tons; kerbs 30,458 feet; "randoms" 2,610 tons; broken stone, size $2\frac{1}{4}$ inches, 49,000 tons; size $1\frac{3}{4}$ inches, 57,000 tons; gravel, etc., 59,000 tons. The remainder is described as "rammel" (i.e., rubbish), rough, and topstone, and was waste. Granite chips are made up into paving-slabs at works situated a mile away. Here 3 measures of chips, size $\frac{3}{4}$ inches, are mixed with 1 measure of

Barrow Portland Cement and cast into slabs. It is clear that an unknown but very large proportion of the rock that has been quarried in Britain (estimated on p. 77 at 15,500,000,000 cubic yards) has been, or is being, ground to powder on the roads. Even this is not all. Ancient slag-heaps are now being "quarried" for slag, which, mixed with tar, is in great demand. Slag, although artificial, is made from substances such as limestone, coal, and ores, which were quarried or mined; and therefore the product of mines, and notably coal, in the form of ash combined in the slag and coal-tar, as well as the gangue of ores, is used for road-metal.

The more incoherent materials dug out of the earth, such as clay, sand, and gravel, are also used in part on roads; the clay in the form of new or broken bricks, the sand and gravel for paths and as a surface-dressing for roads.

Important sources of road-metal that must not be overlooked are broken-up boulders and stones picked off the fields. In the areas covered by Bunter Pebble Beds, or the Drift derived from them, the pebbles are for the most part of hard quartzite and are put on the by-roads. Similar hard stones are also collected over the outcrops of other conglomeratic, sandstone, and igneous rocks. In the Chalk districts there are extensive areas covered by Clay-with-flints, which is a *remanié* deposit of clay or loam containing numerous weathered flints. The fields are often extremely stony, and in many cases the flints are picked off every fourth year and sold for road-metal. In other cases, however, picking is done more rarely. As an illustration of the quantity of stones collected, we may give some figures from Deep Mill, Great Missenden, Buckinghamshire, where the stones collected off 15 acres of land in one year amounted to 326 cubic yards, or an average of 21 cubic yards per acre. In this case the flints had not been picked for a good many years,

and the average is therefore higher than would otherwise have been the case. A measurement made by the author on a small area of about half an acre, several miles from Deep Mill, gave an average of 9 cubic yards per acre. This latter figure is equivalent to 9 cubic yards per 4 acres annually.

In Chalk areas Clay-with-flints is often replaced by gravels, in which the pebbles are mainly well-rounded flints derived from Tertiary deposits, but frequently containing a fair number of Bunter pebbles mixed with them. These stones are also picked for road-metal.

Over a very large part of Britain the Pleistocene ice-sheet has left boulders, called erratics, and as these interfere with agricultural operations those sufficiently near the surface to impede the plough are dug up. This operation is carried to a greater depth than might be expected, for after drought or improved drainage the soil shrinks, and boulders catch the plough which were formerly out of its reach. The removal of tilth by wind and rain also lowers the surface-level and brings new stones within range of the plough. Many of the boulders are built into walls round the fields; others have been placed outside gateways for use, when horse-riding was universal, as mounting-blocks. In some districts the erratics, which are for the most part of hard rocks, have been nearly all broken up for road-metal.

Road-cuttings and "Hollow Ways."—In addition to denudation by the wearing away of pavements a great deal of material is removed from road-cuttings. It is quite usual in rural districts for a lane to be sunk for a part of its course from one to a dozen feet below the surrounding fields. Frequently the cutting is the deliberate work of the engineer when laying out the road; but very often it is due to the wearing down of the surface by traffic. It may often be noticed that when a side-road enters an old main road there is a slight drop to the level of the more important road. In many cases this seems to be due to long continued traffic

having lowered the main road below the less important one. The case is analogous to a "hanging valley," formed where the main river has cut its channel too rapidly for the tributary stream to keep pace. Nottingham offers many instances. The old road to Mansfield, near The Forest, is considerably below the surface at either side. In this case the underlying rock is a soft sandstone easily denuded. Of course now that roads are properly made this action will no longer occur, as any relative lowering of a road would be compensated when next it was paved, and in fact the present tendency is for roads to be raised, as time passes, for more road-metal is added than is worn away. The raising of the road-level, the opposite of the case referred to at Nottingham, is often noticeable where an important road passes old houses. These are often seen to stand a foot or two below the street-level. Instances are very numerous, but we may cite the road to Manchester where it leaves Warrington. Houses with cobble-stones in front can there be seen below the street-level and are reached by steps. A similar appearance in colliery districts may be due to subsidence caused by mining, the road-level having been maintained at its original height.

At this point mention may be made of the "hollow ways" belonging to various periods, but mostly formed before modern pavements were invented. The remains of one may be seen at High Wycombe, near and parallel to the road to Amersham. The greater part of it has been filled up and built over; but parts can still be seen as gullies about 12 feet deep. This road may be an ancient British way, for the Amersham road is itself Roman and the hollow way appears to be older. A particularly interesting case is to be seen at Digswell, north of Hatfield, Hertfordshire, where a deep and overgrown gully represents the former Great North Road. The gully is about 15 feet deep by 550 yards long, and part has been filled in and built over. Although this

hollow way is quite like the one at High Wycombe and to all appearances as ancient, it has only been derelict for about fifty years, when it was replaced by the present road. These examples are both sunk in chalk, which being soft is readily worn away.

Sidney and Beatrice Webb in " The King's Highway " remark that about 1600 the growth of London and other towns, and the increase of trade, caused a great increase in road traffic. Goods were usually carried on pack-horses, and this led to the formation of causeways paved with flags or boulders. Parts of these causeways can still be seen; e.g., on the Yorkshire moors between Todmorden and Huddersfield. They were about 2 or 2½ feet wide and there is usually a channel down the centre worn out by the horses' hoofs. In 1739 people riding from Glasgow to London travelled on a narrow causeway with an unmade soft road on either side until they came to Grantham, within 110 miles of London. The growth of London affected traffic all over the country. In 1710 fish was brought daily from Folkestone by 320 fast horses, and in 1740 salmon was brought from Berwick. It is estimated that about the middle of the eighteenth century some 40,000 Highland cattle annually tramped to Norfolk and then, after fattening, on to London. Some 30,000 head of cattle were brought from Wales. In all about 100,000 cattle and 750,000 sheep were annually driven to Smithfield during the third quarter of the eighteenth century. Pigs, geese, and turkeys (150,000 turkeys annually passed over Stratford Bridge), in addition, all helped to keep the roads in a muddy condition.

After the introduction of toll-gates many new (" drift ") roads were formed to enable the droves of cattle to reach London and other towns without using the toll-roads, and this not only to avoid paying toll but because unmetalled ways were less tiring to unshod animals than the high-roads. Many of the crooked lanes, so characteristic of England, originated in this

manner and some of them have become more or less hollowed out by the traffic. This hollowing out of a road is particularly noticeable near a ford, but it is frequently difficult to discover how much of the cutting has been made by an engineer and how much is due to attrition. A road at Linby, Notts., which crosses the River Leen, seems to be a good instance of a cutting made by wear. The ground is a level plain of limestone and as the river is approached the road becomes a cutting about (speaking from memory) 12 feet deep in rock.

Other Modes of Attrition.—Although the abrasion of rocks by Man is most marked on roads, it occurs under other conditions also. In the process of shaping stones for the builder much dust is produced, as also in all abrasive processes, such as the polishing of glass by sharp sand, which is worn round in the operation. Millstones and grindstones of sandstone or emery offer other instances of attrition. There is a stream-bed near Sheffield into which hundreds of worn-out grindstones have been thrown. However, probably the most striking instances, after the abrasion of roads, are offered by the pounding of rocks to extract minerals disseminated through them. In this country the most marked cases are probably associated with lead, zinc, and tin mines, where the "slimes," as they are called, form large dumps. The quantity of material so treated has been roughly estimated in the preceding chapter, and it will be seen (p. 62) that about 29½ million cubic yards of veinstuff was dug up in connection with leadmining alone, much of which was pounded into mud.

In other cases the mineral is used in a powdered form, as in the case of gypsum. "Terra Alba," which is merely gypsum ground to an impalpable powder for use in paper, paint, and other manufactures, represents probably more than half the output of gypsum, Barytes, kaolin (china-clay), talc (French chalk), and

some other minerals are similarly dealt with. Whiting (powdered chalk) is prepared in large quantities, and the whiting-pits at Grays, Essex, are comparable in area with the great Penrhyn slate quarry. Flints also are reduced to impalpable powder for use in porcelain.

Excellent illustrations of the pulverising of rocks are found in South Africa. From the gold-mines of the Rand, by the end of 1910, there had been extracted 156 million tons of hard conglomerate, the Banket. The pebbles of this conglomerate are of quartz, yet the whole mass, pebbles and matrix alike, have been ground to fine powder to extract the gold. The silt is dumped into mounds and when dry is blown by the winds and scattered widely over the surrounding country, though much collects into dunes. We may estimate that a ton of the Banket produces a cubic yard of dust, and so the total bulk of the dust made by the end of 1910 will be about 156 million cubic yards.

The diamonds of South Africa are found in the necks of ancient volcanoes. Four of these occur at Kimberley and have the following areas: Kimberley 33 acres, De Beers 22 acres, Dutoitspan 45 acres, and Bullfontein 36 acres. The material filling the necks is called "blue ground," and after extraction it is spread out to undergo weathering, a process aided by working it with harrows. When fallen to powder it is washed to extract the diamonds, and the mud is dumped into mounds outside the town. When dry it is scattered by the wind, as in the case of the gold-mine refuse.

In early days the "blue ground" was dug out in quarries; but, when these became deep, the walls of the excavated craters fell in, and for a time put an end to operations. Now the "blue ground" is excavated by mining from deep levels running horizontally into the neck from the surrounding solid rock, and the slipped masses from the walls are allowed to subside as the "blue ground" is removed from beneath them. The

landslips from the walls, in the days of quarrying, were on a large scale. One at Kimberley Mine, in 1883, was estimated to contain $\frac{1}{4}$ million cubic yards, and at De Beers Mine there was a landslip in 1885 containing 5 million cubic yards (G. F. Williams).

Up to the middle of 1908 the quantity of "blue ground" extracted from all the diamond-mines of South Africa was approximately 124 million loads of 16 cubic feet, or $73\frac{1}{2}$ million cubic yards. Of this amount Kimberley Mine yielded about $61\frac{1}{4}$ million yards, and the volume of the Kimberley mounds in 1908 would be about 70 million cubic yards.

Quantity of Rock subjected to Attrition.—Owing to the considerable discrepancy between the quantities of road-metal destroyed when calculated on different methods, we cannot give any close estimate. The lower figure was under 6 million cubic yards in 1913 (p. 116), but allowing for rocks not obtained from quarries returning figures of output, i.e., including brick, gravel, slag, stones picked off fields, and broken masonry; also the gypsum, chalk, etc., reduced to dust, the rock powdered in 1913 cannot well have been less than 10 million cubic yards and may have been considerably more. Fortunately the figures are not necessary for our estimate of rock denuded, which has already been calculated in the last chapter (p. 86). In this chapter we are merely concerned with the fate of the minerals and rocks after they have been mined or quarried.

Rocks Totally Destroyed.—A large proportion of the rocks and minerals excavated is totally destroyed. By attrition rocks and minerals are ground to fine powder, but the dust retains at least its chemical composition. When limestone is burnt in the kiln to make lime; when cement-stones or mixed clay and limestone are burnt into Portland cement; when gypsum is burnt to make plaster of Paris; when clay is made into bricks, tiles, stoneware, or other article; when coal is burnt

alone or with metallic ores; even the chemical composition of the rock is altered and new substances are produced. An estimate of the quantities of these artificial rocks will be attempted later on in the chapter on Accumulation.

CHAPTER IV

SUBSIDENCE

As early as the fifteenth century instances of surface-damage caused by mining had come before British law-courts, and there are numerous records of such cases; but the subject of interest has generally been the monetary value of the damage done. This depends on the accident of the subsidence occurring below some important structure such as a reservoir, canal, or railway, where, although the actual subsidence may be trifling, the damage may be very great compared with that under open country, where it is scarcely noticeable. From the geological standpoint, however, the monetary value of the damage does not matter; it is the extent of subsidence, the effects on the strata, the disturbance of drainage and so forth that are the important considerations.

The study of subsidence due to mining is still in an unsatisfactory condition. Although a good deal has been written on the subject it has to be sought in numerous publications and many languages. The work done has been usefully summarised by Messrs L. E. Young and H. H. Stoek of Illinois. They show that theories to explain subsidence vary with the nationality of the investigator, and that very different results have been arrived at in different countries.

In Austria, subsidences in the Ostrau-Karwin coal-field led to Government investigations with a view to finding the principles underlying subsidence. Mining Director W. Jicinsky published a treatise in 1876 and

another in 1884. He became a member of a committee appointed in 1882 by the Mining and Metallurgical Society of M-Ostrau and eventually produced a formula for the calculation of subsidence. The committee considered that there is no depth at which mining can take place without the possibility of surface subsidence, but there is a harmless depth at which mining will produce only gradual subsidence, with the result that buildings are not damaged but settle slowly down. Jicinsky's formula for finding the harmless depth is said to be supported by 80% of his observations. The formula is $s = t + m -$ at which may also be written $a = 1 + (m - s) \div t$ in which s = surface subsidence, t = thickness of " coal rock " exclusive of the coal bed, m = thickness of coal bed, a = average coefficient of increase of volume of the coal rock considered, as a whole. In several cases investigated $a = 1{\cdot}01$.

The term " coal rock " means the bed of rock overlying the coal which is broken in the course of subsidence, with consequent increase of volume. The entire mass of material above the coal rock is believed to settle without increase of volume and is not taken into account in the formula.

Anton Padour also investigated the subject in the brown coal district of Northwest Bohemia and arrived at the formula $H = 46 \sqrt[3]{h^2}$ in which H = vertical height of subsidence, h = height of excavation.

In this formula no notice is taken of depth of mining. Padour found that in the Bruch district, where the covering is firm marl, the angle of fracture depended on the dip of the coal-seam, the angle being markedly greater towards the rise than towards the dip, though the difference due to rise and dip diminishes rapidly with increased depth.

A. H. Goldreich, who also has done much work on subsidence, objects to Jicinsky's formula. Goldreich points out that the so-called " after-slide " of superficial material is not considered. He found " From the

profiles of sunken railway sections of the Ostrau-Karwin coal district it can be seen that these profiles have a parabolic form, that the maximum subsidences are found in the middle of these depressions, and that the amounts of subsidence decrease almost regularly towards the two ends of the curves until they finally become equal to zero." In this district there is a superficial bed of plastic marl as much as 1,200 feet thick in places. Where the coal-measures crop out, the regularity of the surface depressions disappears, and Goldreich thought that we must depend merely upon experience in forecasting subsidences. He discovered that following the vertical subsidence of the marl overlying the mine there is a lateral after-sliding of the adjacent and outlying marl. He emphasised the effect of the elasticity of each stratum. " When the elasticity of the subsiding roof-strata is so great that the latter reach the floor of the worked-out room without any disturbance in the coherence of the superimposed strata, then the volume of these subsiding strata remains unchanged." Goldreich considered that the " harmless depth " has rather a theoretical character because the presuppositions required are very seldom true in practice.

Of German writers the only one we need refer to here is Graff, who demonstrated that drainage does not cause any change of volume of sand, and held that when the water does not carry away any solid there can be no subsidence resulting simply from unwatering. Graff's view has a bearing upon the supposed subsidences in London said to be caused by unwatering the gravel foundations of buildings.

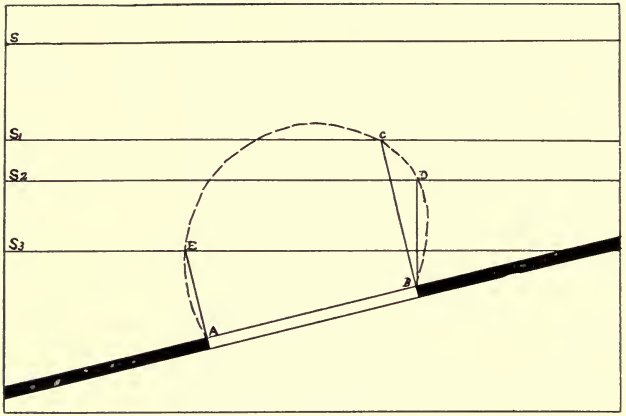
T. A. O'Donahue pointed out that the subsidence caused by the removal of a 6-foot coal-seam is more than twice that produced by mining a 3-foot seam, because in the former case little material is thrown into the gob (the abandoned excavation). He objected to the statement that mining at depths of 1,800 to 2,000 feet will

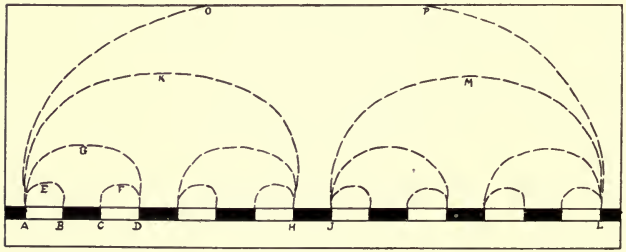
not cause subsidence, his " observations show that the working of a seam, for instance 4 feet thick, will cause the surface to subside about 3 feet if the seam be not greater than 600 feet in depth, and will cause a subsidence of from 12 to 18 inches at a depth of 2,400 feet."

Charles Connor cited observations made in Lanarkshire where the mining of seven seams, approximately 30 feet in total thickness and lying at depths from 900 to 2,700 feet, necessitated the raising of canal-banks 18 feet. Levellings made by Charles Snow at Hickleton Main Colliery showed that subsidence was evident 433 feet in front of a rapidly advancing longwall face, and that total subsidence occurred 666 feet back from the face, the amount of subsidence being 4.5 feet.

Lewis E. Young, after investigating subsidences in Illinois, came to the conclusion that there is no evidence for a harmless depth. In cases where the mine-roof and the material a little above it falls into a free space, it may be more or less shattered; the strata above will sink without shattering and so the subsidence will be passed up to the surface. Young also thinks that, as the weight of the overburden increases directly with the depth, the compression of the gob is greater in deep mines than in shallow mines, and therefore that other conditions being the same, the amount of vertical subsidence is greater above a deep than above a shallow mine.

Probably the most valuable researches on subsidence are those of Monsieur Fayol, whose work explains much that was contradictory in the theories of other writers. Professor Galloway has given an excellent account of the investigations carried out by Fayol, at Commentry in France, on the distance and direction in which the effects of subsidence due to extraction of coal extend. Subsidence is felt for a certain distance (Plate opposite p. 131) above the





DIAGRAMS TO SHOW THE RELATIONSHIP BETWEEN SUBSIDENCE AND COALMINING.
(By permission of the South Wales Institute of Engineers.)

excavation, but may not extend up to the surface. The area affected forms an ellipsoidal block cut off below by the excavation. If this lies horizontally the ellipsoid is symmetrical about a vertical plane through the middle of the excavation, but if, as is usually the case, the coal-seam was inclined, then the ellipsoid is unsymmetrical.

Before Fayol's researches there were rival theories of subsidence: (1), that cracks formed vertically above the excavation, and (2), that cracks formed perpendicularly to the excavation. Neither is correct. In the upper figure, if A B represents the excavation in an inclined coal-seam, A B C a vertical section of the block of strata affected by a subsidence, and S_3 is the surface of the ground then the line A E, passing through A and the point where the ellipse bounding the block of disturbed strata cuts the surface of the ground, will be practically perpendicular to A B when the excavation is not far below the ground; and E where it cuts the surface marks off the limits of subsidence. If the excavation is at a greater depth, so that S_2 represents the surface-level, then the line B D corresponding to it as A E did to S_3 may be vertically above B. If S_1 is the surface the ellipsoid is cut at C, where B C is perpendicular to A B. Finally, at a still greater depth, the surface-level, S, may not cut the ellipsoid at all, and there is no subsidence at the surface. The diagram explains how the rival theories have arisen; it is a question of the depth of the excavation below the surface, whether the area of subsidence ends vertically above or is otherwise related to the excavation.

The effect of pillars in supporting the roof of a mine is shown in the lower figure, taken from Professor Galloway's paper. If A B, C D are the parts excavated, and B C is a pillar, the subsiding blocks are shown in section as A B E, C D F. When the pillar is removed the block A D G subsides. When the pillar

H J is left the subsiding blocks are A H K and J L M. When the whole seam from A to L has been removed the subsiding block is A L P O. As shown, there would be no subsidence of the surface in the former cases, but in the last case the ground between O and P would subside; the top of the figure representing the surface-level.

Experiments made by Fayol with beams, representing strata, showed that the lowest bed over the excavation bends most, and those above in decreasing amount upwards until bending is no longer visible. Spaces are left between the strata, but it is clear that the bent strata may break under sufficient strain. The researches show that subsidence is great when the seam is thick and also when the excavation is near the surface. An excavation at a great depth might have no effect on the surface if sufficient pillars were left to support the roof (see Plate). In practice, however, it is almost impossible, at great depths, to prevent the workings closing in after they have been abandoned and the pillars crushing under the strain. If this happens, the area of the excavation would be, in general, so large that what may be called the dome of disturbance would reach the surface.

Fayol's results are not universally accepted, and it is evident that there is still a great deal to be discovered about the mechanism of subsidence caused by mining. The dip and character of the strata, the presence of faults, the depth of the mine, all introduce new factors into the problem, and further observations are required. It appears that if the overlying strata shatter and fall in they will pack the vacuity and there will be a harmless depth for mining, but when the overlying strata do not shatter but sink as a whole, there may be no harmless depth, or at any rate it will be much deeper than in the cases where shattering occurs.

Subsidence is partly prevented by careful packing of the waste stone into the excavations. Broken rock

is usually rather more than twice as bulky as the solid rock, and under pressure it is sure to contract. Monsieur Fayol has made experiments to find the amount of compression of crushed materials under various pressures. The following table gives the results.

Rock	Space occupied by broken or crushed rock under a pressure of			
	100 kg. per sq. cm.	200 kg. per sq. cm.	500 kg. per sq. cm.	1000 kg. per sq. cm.
Clay	100	90	75	70
Shale	128	116	110	97
Sandstone	136	125	120	105
Coal	130	125	118	109

Space occupied before being broken, 100 in each case.
100 kg. per sq. cm. = 1,422 lbs. per sq. in.
A pressure of 100 kg. per sq. cm. corresponds to a depth of 500 metres;
200 kg. per sq. cm. to a depth of 1,000 metres, and so on.

We may say that ordinary materials, such as shale and sandstone, after having undergone an increase of volume of 60%, undergo a shrinkage of about 30% in mines between 100 and 300 metres deep (328 to 984 feet), leaving them with a volume about 12% greater than that of the compact rock from which they were obtained. Moreover, the materials stowed are very unequally compressed; in some places they are practically loose, in others crushed and solidified by the pressure. The action of water is also important: in its presence pressure is no longer necessary to fill up the voids and reduce the " stowing " to a high degree of density.

The hollow produced at the surface of the ground by subsidence is usually concave in the centre and convex on its edges. The convex part has been stretched and cracks are produced which close as the subsidence extends, and are succeeded by others on the new convex edge.

Professor Galloway sums up the results of Fayol's work as follows:

"The amplitude of the subsidence diminishes in proportion as the workings are deeper below the surface. The diminution is proportional to the depth.

"Above the workings of a seam 1 metre (3·28 feet) in which stowing is not employed, subsidence is not appreciable at 200 metres. If the same seam were worked with stowing, the subsidence would cease at 80 metres above it. If the width of the excavation were reduced to 40 metres *with or without stowing* the zone of subsidence would not extend upwards to a greater height than 80 metres.

"In working a bed 4 metres thick the movements of the ground above the workings would be as follows:

In an indefinitely large area of workings	
without stowing	800 metres
with stowing (which shrinks 40%)	320 ,,
Area worked restricted to 50 metres wide	
without stowing	200 metres
with stowing	100 ,,

These figures have no pretence to absolute exactness, but they appear to be applicable to cases in which beds of sandstone constitute the principal part of the overlying strata, and the inclination does not exceed 40 degrees."

In one case a coal-seam 46 feet thick, dipping at 34°, was worked in horizontal slices, each 8 feet 2 inches high and stowed with sandstone and shale. Two slices were taken out. During the working of the first slice the sinking of the surface proceeded gradually. When the second slice was taken out the sinking increased considerably. The area of the subsidence is about four times the area worked in the seam and the greatest amount of subsidence is 3 feet $4\frac{1}{2}$ inches, or about one-fifth the height excavated. The depth to the bottom of the excavation is 326 feet.

The following table, modified from Young and

Stoek, gives the ratio between the vertical amount of subsidence and the thickness of the material removed, at various depths and localities.

Depth in feet.	Percentage subsidence	Thickness of material removed	Locality	Authority	Filling.
360	70	5.0	England	S. R. Kay	
990	64	3·5	,,	,,	
650	68	5·5	,,	Dixon	
748	19	7·5	France	Fayol	Stowing
2,600	0	13	,,	,,	Harmless depth without stowing
1,040	0	13	,,	,,	,,
390	40	7	England	Gresley	33% of seam put in gob
1,500	30	5	,,	Hay	Stowing

The usual method of reducing subsidence is to pack all waste material into the excavation and such waste is often spoken of as "gob." Messrs W. Griffith and E. T. Conner, who made a special study of the conditions at Scranton, Pennsylvania, which is situated over old workings, say: "Most coal beds consist of interstratified layers of coal, fireclay, slate, and bony coal, the latter three comprising the principal refuse material of the mine. In these beds, in which it is necessary to remove some of the roof rocks or take up some of the floor of the mine in order to obtain height sufficient for the mules and the men to travel along the roads, much mine refuse is produced, which is stored in the chambers. In beds less than four feet thick many chambers are filled with mine refuse or gob from floor to roof. In places this gob is merely thrown in carelessly or is shovelled in; in other localities it is packed as tightly as possible by hand. When there is much interstratified fireclay or bone in the coal beds there will be larger quantities of the gob, and the thinner the bed the greater will be the quantity of mine rock raised or taken down for roads. The supporting

value of stored gob depends upon the compressibility of the material of which it is composed."

Griffith has patented a method of preventing subsidence by blasting the floor and roof of the worked-out mine. As loose rock occupies from one and two-thirds to twice the volume of the same weight of solid rock, Griffith proposed to blast sufficient rock to yield the necessary stowage. He estimated that in the case of beds under 6 feet in thickness it would be necessary to blast the floor and roof each to a depth equal to the thickness of the coal-seam. The method of blasting rock for stowage, from the hanging and foot walls, is commonly used in metalliferous veins.

Hydraulic Packing.—A very important method of avoiding subsidence is to fill the mine-workings with fine material carried by water through pipes. The method is said to have been first used in 1884 to extinguish a fire near Shamokin, Pennsylvania. Two years later it was used at Hazleton, in the same State, to support overlying strata. The materials that have been used include black carbonaceous shale, crushed refuse from coal washing plants, ashes, sand, gravel, clay, loam, granulated slag, and crushed rock. In practice the pipe carries about 90% of water and 10% of material. After some 200 to 400 cubic yards have been deposited the filling is interrupted for about eighteen hours to allow the material to settle; during which period the water seeps out and the material shrinks from 1 to 10% in volume.

The method cannot be used if there is clay below the coal, as the water would soften it and tend to produce a " squeeze." Also there must be a supply of suitable material to use for fillings. It is doubtful if hydraulic filling can be successfully employed where longwall mining is adopted, or where the strata are flat, but it enables the pillars to be got in pillar and stall working. In Upper Silesia more than 100 collieries have employed hydraulic filling, and subsidence has

been reduced from 30-70% to 0·3-7·8% of the height of the seam. In 1914, there were 27 collieries in Silesia using the method. In that country it is usual to dig sand with steam shovels and transport it by railway to the mines. In the Saarbrucken district hydraulic filling is used in iron and potash mines as well as in coal-mines.

In Britain the only moderately extensive installations at work are at Motherwell, but there are a few small installations besides. The method has been used on a small scale at the Crowgarth iron-mine, in Cumberland.

At Scranton, Pennsylvania, it was proposed to build a new railway depot over old coal-workings. A borehole was made and a six-inch pipe put down through which 9,400 cubic yards of sand were flushed. In the same town ashes were flushed down into the old workings under a new power-house, and in 1916 the Electric Company was sinking a shaft down which their furnace-ashes are to be dumped into the old workings, to avoid the expense of haulage.

Pneumatic filling has been successfully employed at several mines in the Lake Superior copper district. In addition to the waste material discarded in the stopes, sands from the stamps and tailings from the concentration plant are brought a distance of eighteen miles and discharged by compressed air into the worked-out stopes. The method previously used was to supplement waste rock from the stopes by rock blasted out of the walls.

In some cases piers of masonry or of concrete are used in mines. In the Tilly Foster Mines no less than 20,189 cubic yards of masonry were built underground. In a zinc-mine in the United States, six concrete piers were constructed, 35 feet high by 16 wide and 20 long, at a depth of 150 feet from roof to surface. The concrete was made of six parts of stamped rock to one part of cement.

The Commission that reported upon the landslide at Turtle Mt., Frank, Alberta, estimated that, under average conditions, settlement would be 5% of the thickness of the bed if ordinary sand was used for stowing; an inappreciable amount if ground slag was used; 10 to 15% with loam, sandy clay and ashes; and 40 to 60% with dry packing. This Commission also reported that the coal-pillars left at Turtle Mt. merely served to delay the process of movement, for that under the great pressures due to depth, shales, such as here constitute the hanging wall, will " flow " and seal all openings.

In South Africa there has been subsidence over the Rand gold-mines where the depth of the workings has been not greater than 710 feet below the surface. It is believed that workings below 1,000 feet in the Rand will not cause any subsidence.

In Pennsylvania the city of Scranton is estimated to have had 177 million tons of coal excavated from beneath it during the 75 years of active mining. This quantity represents a volume of 198 million cubic yards, an amount equal to the total amount of rock excavated in making the Panama Canal. Under a part of the city there are eleven important beds of coal, having an average aggregrate thickness of 58 feet. In the anthracite field, in the same State, there are deep pockets (" pot-holes ") of sand extending a long way below the glacial deposits that cover the surface. When subsidence affects a " pot-hole," water may seep into the mine and there may be an inrush of sand and water. In December, 1915, an accident of this kind occurred at Prospect Colliery, Lehigh Valley, and it was estimated that 140,000 cubic yards of earth and 3 million gallons of water rushed into the mine. Similar accidents are known in England in the Cumberland-Furness iron-mines.

Instances of subsidence due to mining are very numerous in Great Britain, but it is difficult to estimate

the extent of the depression in a particular case. Buildings, railways, bridges, tunnels, canals, reservoirs, roads, water- and gas-mains all show damage. The subsidences due to brine-pumping are treated of later on (page 146). Subsidences similar to those of Cheshire have occurred in the salt-field of French Lorraine, which has an area of about 9 × 19 square miles. The salt-beds are there from 33 to 230 feet in thickness and lie at 300 feet or more from the surface. At Stassfurt, potash-mining in beds 50 feet thick, dipping at an angle of 40°, has caused serious subsidences.

Subsidence may commence immediately after the removal of the mineral, or not until some months have elapsed, and it may continue from two to thirty years, the subsidence being slower when the mining is deep.

The effect of subsidence will, as a rule, be greatest towards the middle of a coal-field that is basin-shaped, with the newest measures towards the centre, where in consequence a number of workable seams will usually be found one above another. In this country as many as twelve coal-seams have been worked from a single shaft, although, owing to the high dip in the particular case referred to, all the seams are not sunk through in the shaft, but are intersected by a main level.

Subsidence will usually be considerable where there are several workable seams over one another, not only because of the total thickness of coal removed being greater than for a single seam, but also on account of the repeated disturbance of the overburden when mining at different levels.

According to a recent paper by Mr W. D. Lloyd, the theory that there is a harmless depth has not been well received in Britain. He says that it is generally recognised that, except where the area undermined is comparatively small, the surface must ultimately be disturbed, although the subsidence may be so gradual

and uniform that it is unnoticeable. He quoted Mr J. A. MacDonald's statement that coal had been worked for at least a century and a half under part of a city in the West of England without causing any damage to buildings. Mr Lloyd points out the important effect on subsidence of old workings in overlying strata. Although the strata above the seams previously worked may have settled to a position of rest, they will be more easily disturbed by subsequent workings than if they were in their original condition. It is usually found that the amount of subsidence in such cases is greater than is produced in virgin ground. The new subsidence may also break down pillars in the old workings and so cause serious damage.

Subaqueous Mining.—In many cases minerals have been mined under the sea. In Britain coal is mined off the coast of Northumberland, Durham, Carmarthenshire, Flintshire, Cumberland, and Linlithgowshire; and metal-mining has been carried on off the coasts of Cornwall and Lancashire.

The workings that extend farthest seaward are probably those at the William Pit, Whitehaven, where in 1901 they extended 19,000 feet beyond high-water mark. At Workington, in 1837, the sea broke into a mine in which insufficient pillars had been left. Under the sea only about one-third of the coal is extracted, as a rule, and mining is limited to places which have a considerable thickness of strata above them; but in certain cases the whole of the coal may be extracted. The effect of subsidence under the sea is to deepen the water, if the coast-line rises sharply, and to submerge a narrow strip of land if the coast-line is low.

Subaqueous mining is carried on extensively in Japan, New South Wales, Cape Breton Island, Newfoundland (for iron) and other countries.

Effect on Surface-Drainage.—The effect of subsidence on land-drainage depends on the shape of the surface. In an area of high relief, drainage changes

may be trivial, even after considerable subsidence; but when the ground is low-lying, important changes in the drainage may ensue. In the Middle West of the United States there are areas where coal has been mined under prairie land which is so flat that the natural drainage is very sluggish. A subsidence of only a few feet causes large sheets of water to stand for months, to the great injury of farmers.

Near Wigan, Lancashire, there is a large area of land under water from which a few dead trees emerge. In this area, as the ground is flat and low-lying, the subsidence has been sufficient to prevent rain from flowing away and to cause it to form a lake.

I am indebted to Mr T. C. Cantrill for notes of a case of subsidence that he has measured in South Staffordshire. About two miles north-east of Walsall, at Stubber's Green, a lake has been formed in the interval between the date of the Ordnance map (Revision of 1900-01) and the date of observation in 1911. The lake, covering approximately 97,750 square yards, is situated on a site shown as land on the map made ten years previously. The depth of the water is unknown, but is at least sufficient to float a boat. The lake is roughly rhomboidal and is bounded on the north-east by a high-road for about 250 yards. Across the road was a swamp also formed since the survey. In the neighbourhood are other sheets of water, but they are not easily measurable.

Mr T. H. Whitehead notices that on the western side of the Netterton Tunnel (canal) the subsidence has been about 40 feet. Immediately below the tunnel the coal has been left unworked, but beyond its margin it has been got, with the result that the land supporting the tunnel now stands up as a ridge, rising some 40 feet above the ground to the west, which has subsided. On the east of the tunnel the effect is similar but not so obvious.

Fissuring of the rocks caused by subsidence may

allow the escape of water from a permeable bed, such as gravel, and cause wells and springs to become dry.

Many of the coal-seams mined in Britain are comparatively thin, e.g., 2 to 4 feet, and it is necessary to remove much additional material in order to allow room for the men to work, and more particularly for the underground roads. In the aggregate a mass of rock equal in bulk to half that of the coal has probably been extracted. If, as already stated (p. 24), the total output of coal in the United Kingdom since the earliest times is roughly 12,667 millions of cubic yards, and we add 50% to allow for the bulk of stone brought up with the coal, we find that 19,000 million cubic yards have been excavated by coal-miners since the earliest times. The volume of subsidence, however, due to coal-mining up to the present is but a fraction of this amount because a great part of the excavation is filled up (1) by stowing waste (2) by the breaking down of strata and resultant natural packing. Since coal-mines tend to become deeper as the mineral becomes exhausted near the surface, the amount of subsidence produced by mining will be less than that in the past. Professor Galloway's statement above (p. 134) shows us that as much as 13·12 feet of strata can be entirely removed without any subsidence following, provided that the workings are not less than 2,624 feet below the surface. We already possess many collieries deeper than this and in the future we may expect new shafts to extend down to about 4,000 feet. With stowing, if Monsieur Fayol is right, there would be, as a rule, no subsidence at all caused by deep collieries. Instead there would be a belt of shattered strata up to 2,000 or 3,000 feet in thickness and holding water like a sponge. Such a belt differs from a smash-belt made by Nature in its spongy character. Those formed by natural forces occur, as a rule, in regions of folding, where the rocks have been broken under the orogenic forces. These broken masses have been kneaded by enormous

pressures and cemented by percolating waters into solid rock, as compact as the other rocks of the district.

By adding together the reserves of coal in England and Wales, as given by Dr W. Gibson for each coal-field, we find the total to be 86,387,891,000 tons, of which over 2,000 millions are under the sea, off the coasts of Cumberland, Northumberland and Durham. The area of the coal-fields is approximately 4,682 square miles; including an area in Northumberland containing coal sparingly, it becomes 5,900 square miles. In Scotland the area is about 2,300 square miles and the reserves 11,923,000 tons.

Supposing that the whole of this coal is eventually dug and that half its bulk of stone has to be excavated in order to extract the coal, the total future excavation in England and Wales would be about 126,580,500,000 cubic yards, under the land surface, that under the sea being omitted, and under Scotland 17,884,500,000 cubic yards. If the excavations were spread uniformly over the area of the coal-fields, which of course would not be the case, it would amount to $8\frac{1}{2}$ yards over the entire area of 4,682 square miles. For Scotland the excavation would amount to about $2\frac{1}{2}$ yards over the area of the coal-fields, taken as 2,300 square miles. These figures apply to the future, and are additional to the 19,000 million cubic yards already excavated.

The amount of subsidence cannot be estimated, because, not only would there be packing of the strata, but the depth of much of the excavation would be at depths approaching 4,000 feet from the surface, and this part might not produce subsidence at all. The waste, estimated at 50% of the coal, is to a great extent left in heaps on the surface, or spread about. As it is fragmental material it occupies much more bulk (see p. 133) than it did in the mines, and this will help to diminish the nett subsidence.

Subsidence in Cumberland-Furness Iron District. —In the hæmatite mining district of Furness and

Cumberland the bulk of the ore occurs between 50 and 500 feet below the surface. Mr Bernard Smith, who has made a special study of the iron-ore of this district, has kindly supplied me with some notes on the subsidences. In the " flats " (horizontal tabular masses), the average thickness of ore removed is about 20 feet, in the veins it rises from a minimum of about 50 feet to a maximum of 100 feet vertical. The ore mostly occurs in limestone covered by Drift, of very variable but usually considerable thickness. The extremely irregular and sporadic mode of occurrence of the ore leads to correspondingly irregular subsidences.

The site of the first workings at Montreal Mine, Cumberland, is occupied by a deep hollow nearly 200 by 100 yards in area. The ore-body worked at No. 5 pit, Montreal, is a vein-like mass situated on a fault and its excavation causes another deep subsidence. Many such hollows have been filled with waste materials. In other cases, where flats have been worked fairly near the surface, the latter has subsided more or less evenly, and in some cases the depth of the hollow is almost equal to the thickness of the ore removed; for example, at Longlands Mine, where a flat near the base of the Carboniferous Limestone rises gently eastward to crop out beneath surface-gravel. The ore worked out averaged from 20 to 24 feet in thickness and the vertical subsidence is probably from 16 to 20 feet. At this mine there is a subsidence covering some 400 by 200 yards, east of the River Ehen, which has frequently burst its banks and flooded the low-lying ground. One of these bursts occurred in 1909 when the rush of water cut great gashes in the surface-gravels to the north and deposited the *débris* in delta-form in the subsided hollow to the south. The shafts also were invaded. After heavy rains the hollow is occupied by a lake.

At Crossfield and Cleator Moor Mines it has been found necessary to carry the River Keekle in a timber

and concrete culvert across the subsided area. Cases of subsidence are very numerous. Between Cleator Moor and Egremont the scattered ore-bodies worked out or working, cover a total area of from five-sixths to one square smile.

In the Furness division of Lancashire conditions are much the same. The Park Mines ore-body had an area of roughly 500 by 200 square yards at the surface and descended to a depth of about 240 yards. Assuming that the ore-body was an inverted cone or pyramid and assuming a quarter of the mass was waste rock and sand, left in the ground, the bulk removed would be 12 million cubic yards, and this is roughly the volume of the great pit covering the site.

South of Askham there are numerous subsidences due to the removal of similar but smaller isolated bodies of ore, whilst in the region north and north-east of Dalton they may be counted by dozens, the pockets varying in size from 20 to 100 yards across. It may be taken that in most cases the thickness of the ore-body was at least as great as the width at the surface; usually it is greater. In fact the ore-bodies appear to be located in pre-Triassic swallow-holes, and after removal of the ore a cavity resembling the original swallow-hole remains, but is less deep because of the *débris* left after mining. Generally the ore has been cleaned right out, leaving only surface drift, pit-timber, rock fragments, etc., to partially fill the cavity. Many of the hollows have been filled up by man and the site forgotten.

At Hodbarrow there is considerable subsidence of the old mine east of the Annie Lowther fault, but the area, which contained veins and irregular-shaped bodies, has not collapsed so generally as over the New Mine; moreover large pillars have been left. On the New Mine there has been a great collapse, brought about in stages as the ore was worked seaward. The total area of the subsided ground is roughly 120,000

square yards, and the subsidence extends to a maximum depth of 80 or 90 feet and an average depth of about 70 feet. The volume of the cavity is therefore about 2,800,000 cubic yards. The maximum thickness of the ore was 108 feet at a point beneath the old sea-wall; usually it varies from 50 to 80 feet in thickness. The sea-wall has now collapsed into the cavity, and a new embankment, the Outer Barrier, has been built to reclaim part of the foreshore and enable ore to be excavated without danger of the sea breaking in. This disaster had previously happened about the year 1898 when part of the foreshore and of the old wall subsided.

Subsidences in Salt-working Districts.—Salt deposits offer special problems of subsidence, for, as the mineral is for the most part pumped up in solution, and not obtained by mining, a cavity is left without any support from pillars; the only part left in the ground being the insoluble residue.

The British deposits of salt are situated in Cheshire, Worcestershire, Staffordshire, Yorkshire, Co. Durham, Lancashire, Somerset, Shropshire, the Isle of Man and Carrickfergus (in Ireland). Of these much the best known are those in Cheshire; the Middlesbrough deposits, although very important, being of comparatively recent discovery, while those of Cheshire have been worked for many centuries.

The salt-beds of Cheshire are much thicker than coal-seams. Under Northwich the salt consists of two beds separated by from 20 to 26 feet of marl. The upper bed, the Top Rock, is more variable than the lower or Bottom Rock. Each attains a maximum thickness, at Northwich, of about 90 feet, but as a rule the Top Rock is much thinner than this and the Bottom Rock also varies, though to a less extent. What are apparently the same beds are found at Winsford, some five miles away; but the thickness is greater, being about 239 feet in all, while the greatest thickness of salt known in the country is found at

Plumley, about three miles east of Northwich, where there is nearly 600 feet of rock-salt. At Middlewich, Wheelock and Lawton, little is known of the thickness of the salt; but at Heatley (Lymm) about four miles east of Warrington, it is about 200 feet. The continuity of the beds has not been proved, but is highly probable; and the presence of salt-springs at Audlem, Dirtwich and many other places, and of thick salt-beds near Whitchurch, points to an extension into Shropshire.

Brine-springs had been known for centuries at Northwich when, in 1670, the top bed of salt was discovered there and was mined from about 1730 until 1800. In 1781 the lower bed of salt was found and after 1800 became the main source of rock-salt. The quantity mined, however, has become very small in comparison with the salt obtained by the evaporation of brine and known to the trade as White Salt.

The proved extent of the Top Bed at Northwich is an oval area about $1\frac{5}{8}$ by $1\frac{1}{4}$ miles, with a thickness attaining in the centre a maximum of 90 feet; while the Bottom Bed has a similar maximum thickness and is worked over an area of about four square miles. It is more uniform in thickness than the Top Bed, which has been greatly denuded at its upper surface. In the old days the excavations were from 30 to 36 feet high and the roof was supported by pillars, but the modern mines are from 15 to 18 feet in height only.

For a long time Northwich has been remarkable for its subsidences. Streets and houses fall in and require repeated repairs to keep them fit for use, and large meres (the flashes) have developed and are continually extending. These subsidences, which occur also in other salt-districts and particularly in Winsford, are due to the mining of rock-salt and the pumping of brine. The natural brine-springs removed, from the surface of the bed, a small quantity

of salt dissolved by water percolating through the superincumbent rocks and forming a layer of brine over the mineral. The upper part of the layer was far from saturated, and it was this highest layer that oozed out at the springs and removed a relatively inappreciable quantity of salt. In 1533, 1659 and 1713 small subsidences were recorded, and they were probably due to the removal of salt by the springs, i.e., in three centuries there were three small subsidences from natural causes. More than a hundred times as much subsidence now occurs in ten years as formerly in three centuries, the difference being caused by the action of Man.

The causes of subsidence are two: (1), the falling-in of old rock-salt mines; and (2), the removal of the salt in solution as brine. The first cause is now by much the less important. The most serious case of this kind was due to the collapse of a shaft at Willow-cum-Twambrook. The hole produced is about 450 yards in circumference. In early days subsidences were always caused by the collapse of mines. Sometimes the pillars of salt were not large enough, or at other times they were partially removed when the mine was approaching exhaustion. As a result, the shaft, being the weakest place, crushed in, and water was enabled to get into the mine and dissolve the pillars. A conical hole was formed; but the marl above the salt falling in, sealed it for a time and prevented access of water. However, the check was but temporary; and gradually, as the water percolated in through the broken-down shaft more and more pillars were dissolved, and the subsidence extended until the whole mine collapsed. The collapse of a mine and the inrush of water put a great strain on the boundary walls, and presently the water ate its way by solution of these salt walls into adjacent mines and caused their collapse also. By 1887 all the mines in the upper bed had been destroyed except one, and all the present mines are in

the lower bed, with the exception of one at Northwich and one at Winsford.

The production of salt by the evaporation of brine has grown enormously. In early days the brine rose to a considerable height in the wells; but, as production increased, the level was lowered until it fell to the surface of the salt. Afterwards the brine pumped came from streams that flowed over the rock-salt and dissolved it in their course until the water was saturated. The surface of the salt-bed became worn into deep gullies in this manner, and subsidences began to be noticed over the lines of the channels. Water, on reaching the salt, soon becomes saturated and then exerts no further solvent action; but when it is pumped up, the space left is filled by freshwater, which dissolves salt to saturation, and a continuation of the pumping results in rapid solution of the salt. A striking illustration of the slowness of natural denudation of salt is the case of the salt mountain of Cardona, in Spain, which is said to waste under atmospheric agents by only 4 inches in a century. Again, at Kohat in India, rock-salt is said to waste only 2 feet in a century.

At Northwich, a considerable part of the town is situated over the salt-deposits, and subsidences are naturally most noticeable amongst buildings. Subsidence is mentioned by Ormerod as occurring there first in 1819. The subsiding part of the Witton Brook, which in 1790 was 130 yards long by 90 yards wide, had become, in 1837, some 1,230 yards long by 130 yards wide. In thirty-two years part of this area had sunk 24 feet. Ormerod describes its extent in 1848 pretty fully. By 1880 the sinking region along the brook had increased to an area 4,370 yards by 1,470 yards wide at the broadest, and an area of 1,200 acres was affected, while at Winsford over 1,500 acres had subsided. The Flashes (meres) when sounded, show troughs in the stepped sides, and may be 30 or 40 feet

deep. If the earth is tenacious they may fall in suddenly; but more usually funnel-shaped holes arise, which widen by degrees. At Marston and near Dunkirk, Northwich, land and roads sunk 40 feet in the period from 1877 to 1888, and what were green fields are now covered by 15 to 30 feet of water. Numerous striking instances of subsidence are given by T. Ward and others, which need not be quoted here. Ward writes that in 1900 the Dunkirk Lake was about 30 acres in area and was daily extending in spite of several scores of thousands of tons of earth and stones having been thrown in. The depth was from a few to 100 feet. The large flashes alongside the Weaver had been nearly filled up in 1898 with waste from Brunner Mond & Co.'s Chemical Works.

In 1880 the mines in the Dunkirk district were pumped very low and there was a great collapse, owing to the loss of the support afforded by the brine. The Cranage Brook got through the old top-bed mines into the bottom mines and through a thin partition wall into Platt's Hill mine, which was being worked. This mine was about 6 yards high and covered 15 acres. The Cranage Brook, as well as the Wadebrook and a great quantity of water from the Weaver, ran in for many hours. The result was the formation of a large lake, which has continued to increase in size. In 1893 the quantity of brine pumped from the Dunkirk mines was enormously increased and rapid subsidence occurred, causing the lake to extend towards the shafts of the Platt's Hill mine. These collapsed, leaving a hole about 90 feet across by 15 feet deep. When the lake reached the hole, although the shafts had been practically filled up with rubble, etc., the water dissolved out salt. At one time the depth of water over the shafts was fully 200 feet, and for a long time it remained above 160 feet over a considerable area. The earth on all sides of the hole slipped in, and attempts were made to choke it by sinking over the site some

SCENERY OF NORTHWICH, CHESHIRE, CAUSED BY SUBSIDENCE DUE TO THE PUMPING OF BRINE.
(1)THE TOWNSEND ARMS, NORTHWICH.
(2)SITE OF THE TOWNSEND ARMS, 1917.
(3)ROAD FROM NORTHWICH TO WARRINGTON, SHOWING CRACKS.
(By permission of G. W. Malcolm, Esq.)

old canal-boats full of cinders, as well as by putting in thousands of tons of dredgings from the Weaver and Manchester Ship Canal. Fully 100,000 tons of earth and rubbish have been dumped and over 250,000 tons of earth have slipped in; but the depth is 60 or 80 feet over a considerable area, and the land is still cracking and sliding. On the west the subsidence has been so great and rapid that it seems certain that some mines in the top bed, abandoned over a century ago, have been reached. The strata are flooded and the brine has risen until it stands considerably above the surface of the upper rock-salt. Between 1880 and 1898 a lake of over 20 acres, with a depth of 1 to 50 or more feet, was formed. The Marston or Neumann's Flash covers more than 12 acres and is very deep in places. Both lakes are constantly extending. In Marston district there are ten flooded mines covering more than 60 acres; in the Dunkirk district ten flooded mines cover about 60 acres also. Between the two districts there is, or was, a narrow rock-barrier, which may at any time be broken through. These bodies of brine contain 720,000 tons, or 450,000 cubic yards of salt (at 32 cwts. per cubic yard). This is equivalent to a mass covering 18 3/5 acres 5 yards deep. But as the rock-salt beds are 54 yards thick in this region, about 2 acres of the two beds, allowing for marl in the rock, would suffice. The great thickness of the deposits explains the considerable depth of the lake that is forming.

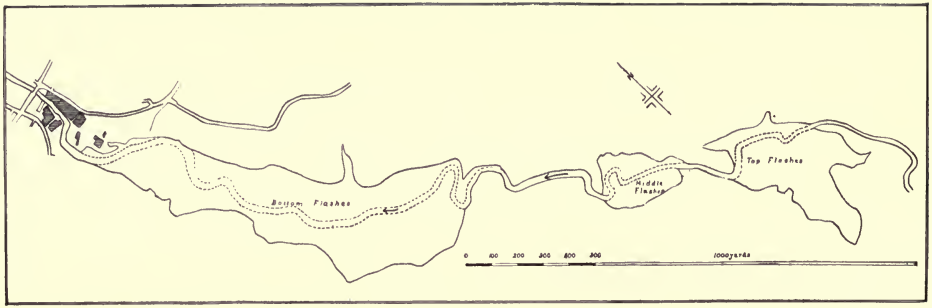
Mr John Rigby stated in evidence in 1906 that soundings taken in Ashton's Flash in 1896 gave the following depths of water along a straight line: 110, 96, 92, 85, and 80 feet. In 1898-9 the soundings were 41, 47, 51, 51, and 50 feet, the smaller depths being due to several hundred thousand tons of sandstone, excavated in the making of docks at Liverpool, having been deposited in the lake. In 1902 the soundings were about the same: 47, 47, 48, 50, 50, and 42 feet;

but in the interval, sandstone, in addition to 177,000 tons of dredgings from the River Weaver, had been spread all over the floor. In all about $1\frac{1}{4}$ million tons of waste had been deposited in the lake. The soundings remain much the same, but this is due to waste being put in daily and counterbalancing the continued subsidence. Recently (1906) a depth of 110 feet had again been found in one part of Ashton's Flash.

The greater part of the insoluble residue from the solution of the salt remains below and helps to fill up the hollows with fine mud. This residue is about 25% of the whole mass. In the case of rock-salt-mining there is, of course, no residue; but in this case the parts of the mass most free from impurity are chosen for mining.

Subsidence at Winsford first appeared in 1820, since when it has followed the same course as at Northwich. At the latter place the lakes have little relation to the rivers, because they were initiated by the collapse of the Top Mines, which were grouped in clusters without relation to the surface-drainage. At Winsford, however, the floods began as pools on the river-flat, extending rapidly into a lake, through which the river runs. There are now three lakes at Winsford, the Middle Flash being of quite recent origin. The Bottom Flash ends at Winsford Bridge, which had been raised no less than 17 feet by 1880. Ashes from the salt-pans are constantly being deposited in this lake; but, although it is possible to keep some parts of it shallow, the subsidence is still growing. Doubtless the three lakes will eventually coalesce. The growth of the Winsford flashes is shown on the plate opposite, for which I am indebted to Mr G. W. Malcolm, of the Salt Union.

In 1898 Ward estimated that the total output from Northwich during the previous two hundred years was about 25 million tons of white salt and about 10 million tons of rock-salt. He considered that rock-salt



MAP OF WINSFORD, CHESHIRE, SHOWING THE LAKES ("FLASHES") CAUSED BY SUBSIDENCE DUE TO THE PUMPING OF BRINE.
(By permission of G. W. Malcolm, Esq.)

contains on the average 25% of insoluble residue and so the loss of rock-salt from Northwich previous to 1898 would be about 40 million tons, equal to 25 million cubic yards. I find that a similar calculation for Winsford, from figures given by Ward and Calvert, indicates a loss of 50 million tons, or $31\frac{1}{4}$ million cubic yards from that district, up to 1913 inclusive. From the entire salt-field of Cheshire about 115 million tons, or $71\frac{1}{2}$ million cubic yards, of rock-salt had been removed by the end of 1913.

In a report dated 1873, J. Dickinson said that the subsidence is counteracted to some extent by waste from the works, cinders, etc., but that this may be set off against the loss of salt (about 30%) in manufacture, so that the figures for output give an estimate of the amount of subsidence over the area caused by the removal of salt.

Sinking of the ground will continue until all the salt has been removed. The depth to the salt is about 140 to 180 feet at Northwich, about 200 feet at Winsford, and about 370 feet at Lymm and Plumley, so that in Cheshire the depth of the salt is everywhere relatively shallow, and this of course gives less opportunity for the strata to pack themselves. It is possible that the figures found by Monsieur Fayol for the increased bulk of broken strata (page 133) apply to the salt-measures, in which case the volume of subsidence will be four-fifths the volume of the salt removed; i.e., subsidence will be about 20 million cubic yards at Northwich and 25 million cubic yards at Winsford. It is probable, however, that the soft marly strata collapse with little packing; and if so, the subsidence will be nearly equal to the volume of the rock-salt removed.

According to Ward, the average thickness of the salt in the four square miles worked at Northwich is about 162 feet. The maximum subsidence would therefore be a little less than 162 feet at Northwich. A greater subsidence is possible at Winsford, where the

salt is about 239 feet in thickness, and still more at Plumley where it is nearly 600 feet thick.

There is reason to believe that the salt-beds extend over a very much larger area than was known to Ward and Calvert,[1] and the possibilities of subsidence in the district are greatly increased. Nevertheless, it will be a long time before pumping in the newly discovered districts can cause extensive subsidences. The quantity of salt in Cheshire is so vast that it is likely to be many centuries before it is exhausted, and the full subsidence may never be felt. In that very distant future, however, there is a prospect of an area of some 200 square miles being reduced in altitude by an average amount of 100 feet, which would bring much of Cheshire below sea-level. Even if the sea were kept out by embankments the drainage-water would form a large freshwater lake, parts of which might be, say, 400 feet deep. Already the bottom of the largest flash at Winsford is at about sea-level.

In the Middlesbrough salt-field the output of salt, pumped as brine, up to the end of 1918, was 7,000,645 tons, which, supposing the rock-salt to have the average composition of that of Cheshire, would represent the solution of about 2,916,000 cubic yards of rock-salt. About one-third the bulk, or 972,000 cubic yards, would be left behind as fine clay to help to fill up the empty space. At Middlesbrough there is a thickness of from 863 to 164 feet of rock, much of it massive sandstone, above the salt. Probably, therefore, when subsidence does begin the sandstone beds will break and pack themselves, so that the volume of subsidence will be less than that of the cavity formed. At present there are, presumably, caverns of a total volume of about 2,916,000 cubic yards, about one-third filled with mud and the remaining space with brine.

In the Isle of Man there is a salt-field at the Point of Ayre. Here there are about twenty-one thin beds

[1] R. L. Sherlock, "Rock-salt and Brine."

of salt, the highest 615 feet and the lowest 857 feet below the surface. The total output up to the end of 1918 was only 85,097 tons of white salt.

In Worcestershire there has been considerable subsidence at Droitwich. Salt has been pumped here since Anglo-Saxon times, although the quantity has never been great. At Stoke Prior, about three miles to the north-east, rock-salt was discovered in 1828, and at first was mined, but later on the salt was obtained as brine. The Mineral Statistics commence their account of salt in the county in 1859, and for a considerable number of years combine the Droitwich output with that of Stoke. About 1868 Stoke began to have the larger output, and since then the output of Droitwich has declined, while that of Stoke gradually increased until 1890, since when it has declined. The output of salt from 1859 to 1918 inclusive was 11,650,128 tons, but there is no record of the centuries of output before 1859.

Staffordshire produced a little salt at Weston-on-Trent and Shirleywich, near Stafford, as early as 1686, when Plot records salt-works, but the output was probably trivial. Mineral Statistics first mention the county in 1873, and from that year to 1892 and from 1899 to 1913 the total output was only 752,075 tons.

Preesall, near Fleetwood, Lancashire, has been a brine producer since 1890, and rock-salt has been mined there since 1892. The total output up to 1918 inclusive has been 2,247,022 tons of rock-salt, and 3,679,654 of white salt. These quantities represent the removal of about five and one-third million cubic yards of rock-salt. Small subsidences have appeared in scattered patches.

At Puriton, Somerset, salt has recently been found and brine is being pumped. As yet there is no subsidence.

Total Subsidence.—On page 86 an estimate is

given of the amount of rocks and minerals mined since the earliest times. Some of this material may be obtained from so great a depth that subsidence will not be produced; also subsidence does not seem to be marked in the case of many metalliferous deposits, where the workings are inclined at a high angle and are in very massive rocks. The table on page 135 shows the great variability in the amount of subsidence in the different instances examined. As a very rough approximation we may perhaps take the average subsidence due to mining at all depths at from 30 to 40%. If only 30% the effect on the surface is as if 5,910 million cubic yards of rock had been removed, a quantity that can be added to that quarried. The remaining 70% of space underground, a volume of 13,790 million cubic yards, will be filled with broken fragments of rock, forming masses of breccia with the interspaces filled by water.

CHAPTER V

LONDON

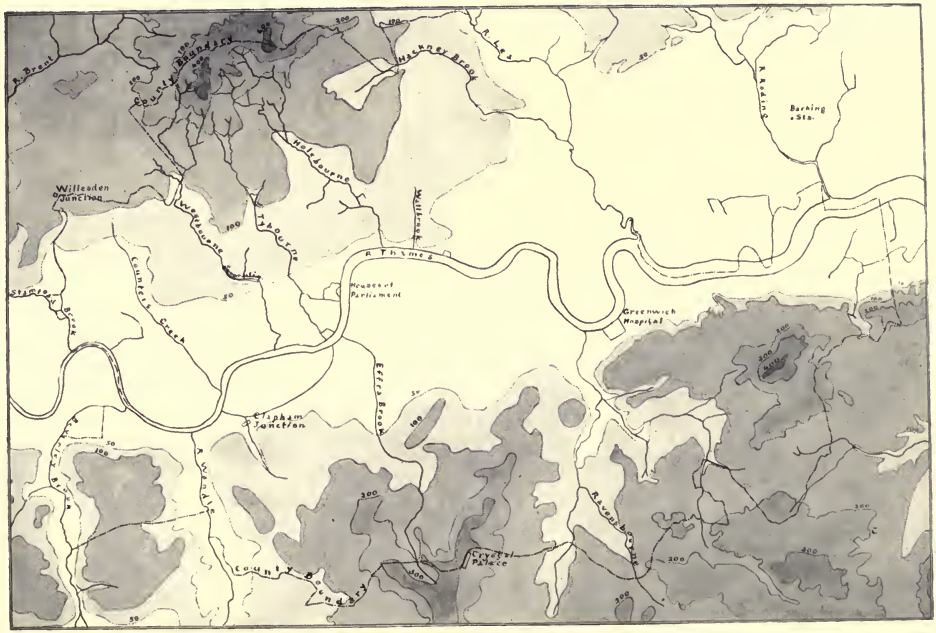
London, the largest city in the world, and with a history extending over some two thousand years, offers an excellent field for a study of the changes wrought by Man on Nature. Before Man settled on the site of London the district formed an extensive marsh, stretching southwards as far as Stockwell and New Cross. Lambeth, Kennington, and Newington were mud-banks, covered at low tide, while at high tide the river flowed directly from Lambeth to Deptford. There is no doubt, says E. Bazalgette, that the Strand, since raised by artificial deposits to a considerable elevation above the bed of the river, derived its name from being literally the strand or foreshore of the river-bed. Thus the river, formerly divided into several channels within the metropolis, has been confined within one deeper channel of more uniform section. The first authentic information regarding the embankment and improvement of the Thames dates from 1367, in the reign of Edward II., when Commissioners were appointed to view and repair the banks.

On the north of London the Hampstead and Highgate Hills rise to 440 and 420 feet respectively, and the ground in front, sloping towards the Thames, was cut into by small streams, the Westbourne, Tyburn, Holeburne (the lower part called the Fleet), and the Wall Brook. The last rose on Moorfields, the others at the foot of the Hampstead and Highgate Hills.

The higher ground between the streams forms hills such as Notting (or Camden) Hill, 130 feet high, and Tyburn Hill, about 90 feet; then beyond the Tyburn is the site of Oxford Circus, 90 feet high. Farther east we have Ludgate Hill with a low plateau extending to the valley of the Wall Brook, east of Cheapside. This plateau was about 59 feet above sea-level. Beyond the Wall Brook comes Cornhill, and it is probable that this patch of rising ground, sloping eastwards to the Lea Marshes, formed the site of the first settlement. To the north of the settlement the Finsbury Marshes extended to the forest that covered Middlesex and Hertfordshire and spread far beyond those counties. On the other three sides the settlement was protected by the Wall Brook, the Lea, and the Thames. In those days the tide reached far up the river and overflowed what is now dry land, both to the north and to the south of the present bed.

A relic of the Westbourne is the Serpentine. The river used to flood Knightsbridge, and opposite Albert Gate a stone bridge was erected, it is supposed by Edward the Confessor. Lower down the stream was a swamp called the Five Fields, now occupied by Sloane Street and Chelsea Bridge Road. At the present time the Ranelagh Sewer carries the river-water in the general direction of the old stream. The sewer was completed in 1834, and can be seen crossing Sloane Square Station.

The Tyburn, or Ayebrooke, flowed through Regent's Park, where the junction of a tributary is still to be seen as a fork in the lake. The stream crossed Piccadilly at Brick Street, where there used to be a water-wheel, and flowed under Buckingham Palace. It then divided into three arms, the middle one turning mills at Abbey Gardens, Westminster. The Abbey stands on its delta. At Marshall and Snelgrove's, Oxford Street, a bridge over the old river was found, also the metalling of the old Tyburn Road,



THE SITE OF LONDON, SHOWING RIVER DRAINAGE IN PREHISTORIC TIMES.
(Based upon the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.)

11 feet below the level of Oxford Street. In 1238 a conduit here supplied water to the City. Finally, in 1812, the stream was incorporated with a sewer.

The Fleet, or Holebourn, was the largest tributary, and its lower part was a tidal estuary up which, at one time, ships sailed as far as Holborn Bridge. Stow says that it was of such breadth and depth that ten or twelve ships' navies at once, with merchandise, were wont to come to Fleet Bridge and some to Oldbourn Bridge. It was still navigable as late as the reign of Edward I. In 1666 the river was canalised, but barges still went up to Holborn Bridge, and a drawing dated 1765, preserved in the Guildhall, shows them moored by Bridewell Bridge. Holborn Bridge, of stone, had houses on both sides in 1560, and in 1673 it was rebuilt by Sir C. Wren. Later the Fleet declined, first to a brook and then to a drain. In early days the river flooded its banks, but these floods died out. It became very foul from City refuse, and in spite of scouring it became choked again. In 1735 the Corporation began to close in the stream, and in 1855 the Fleet was absorbed into the Metropolitan Sewer and is now covered entirely, from source to outfall.

The Wall Brook once flowed past the villas of the City merchants. The earliest map of London, that by Agas in 1560, was published long after the brook had been covered in, about 1473, so there is no record of the brook on any map. It ran from the fens of Moorfields, through the Wall, then across the site of the Bank of England and by the Mansion House. The building of the Wall across the brook ponded up its waters and caused them to form the morass of Moorfields. The peaty alluvium of this district is a result of the Roman Wall. At the National Safe Depository the Wall Brook was joined by the Langbourne Water. It was of considerable width at its mouth, and was navigable, and barges went up as far as Bucklersbury.

The old valley, filled with mud, in places to a depth of 30 feet, passes through Austin Friars, and at this point drained a morass bounded by Colman Street and Old Broad Street. The Bank of England and the Mansion House are built on the mud. In Token-house Yard, garden-paths and tree-stumps were found under a house at a depth of 10 feet below the present surface. The brook flowed in a ravine at least 30 feet deep, and Roman remains have been found at that depth. Enormous quantities of broken vessels and kitchen utensils have been discovered, showing that the ravine was a receptacle for refuse. In 1288 and 1388 the Common Council made requisitions for cleansing it, and in 1598 Stow speaks of it as having been vaulted over and paved and its course forgotten. The soil, says Mr Greening, has been getting drier in recent years, owing to the pumping frequently resorted to on the erection of new buildings and the construction of deep basements (for instance, Lyons' cafe in Throgmorton Street extends 42 feet below the surface) and through the action of shallow wells in Queen Victoria Street.

Fitzstephen, in 1190, wrote: "There is also about London, on the North side, excellent suburban springs, with sweet, wholesome, and clear water that flows rippling over the bright stones; among which Holy Well, Clerkenwell, and Saint Clement's are held to be of most note. These are frequented by greater numbers, and visited more by scholars and youth of the City when they go out for fresh air on summer evenings." For centuries these springs supplied London's needs, until they became contaminated and the first public waterworks was constructed in 1512 at London Bridge.

There are few traces of pre-Roman settlements. The first Roman wall round London took in about 70 acres between Wall Brook and Mincing Lane, on what was practically an island. As the town extended

a second wall was built to take in a much larger area, and this wall was more than three miles long, but included gardens and open spaces. The new wall stood at a few feet distance from the inner edge of a very wide moat, and was founded on a puddled trench. The new wall was 10 feet wide at the base, narrowing to 5 feet at the top, and was 24 feet high.

Fitzstephen (twelfth century) wrote that " London formerly had walls and towers—on the south, but that most excellent river, the Thames, which abounds with fish, and in which the tide ebbs and flows, runs on that side, and has in a long space of time washed down, undermined, and subverted the walls in that part."

The Romans dug up the Thames alluvium to make into bricks, and this practice has since been maintained, until nearly the whole of the alluvium that covered the site of the growing town has been removed and the underlying gravel exposed. The alluvium removed was burnt into bricks and tiles to build London, and, although a great proportion of the bricks have since been destroyed, their fragments have accumulated to raise the general level. The accumulation of *débris* is probably about equal in thickness to that of the alluvium stripped off.

Neither the alluvium nor the accumulated *débris* has a uniform thickness and the ground-level has been altered all over the area. The level has been raised in one place and lowered in another. Broadly speaking, hills are lowered and valleys raised, partly by loose materials working down slopes, partly by the action of engineers in lessening gradients on roads, partly by dumping waste materials in hollows. Nevertheless, although hilly ground becomes somewhat flattened, the original shape of the surface is, as a rule, only toned down, not obliterated. For example, the ravine of the Fleet has been filled up, but the steep gradient at Ludgate Circus still shows where the river used to be.

The thickness of the *débris* or "made ground," as it is usually called, is illustrated by the sections opened up during the construction of the Middle Level Sewer. At High Street, Shoreditch, the "made ground" is 4⅓ feet in thickness; it increases suddenly between that place and Tabernacle Square, Great Eastern Street, to 11¼ feet. The increase continues westwards, and at Old Street, near the end of Bunhill Row, it is 14 feet 11 inches, while at the junction of Old Street with Goswell Road it is 19 feet 9 inches. At St John's Street, north of Wilderness Row, it is only 8¾ feet, but at St John's Square, near the corner of Albemarle Street, it is 21 feet 2 inches in thickness. Then there is a thinning, and near the south-east corner of the Sessions House in Turnmill Street it is only 2½ feet, but a little west of this at Farringdon Street, east of the Fleet Sewer, it becomes 15 feet 1 inch. Thence to the junction of Bedford Row and Theobald Road the *débris* is from 7½ to 16 feet in thickness. At the corner of Hart and Museum Streets there is 7 feet 8 inches, at the corner of Oxford and Newman Street 9 feet 8 inches, at Oxford Circus 20½ feet, opposite the Marble Arch 8 feet, between Albion Street and Hyde Park Station 4 feet, and thence westwards from 2½ to 8⅓ feet in different places.

Along the Low Level Sewer the made ground is mostly from 1½ to 9 feet thick, but at Royal Mint Street, by King Street, there is 17 feet of it, and at Rood Lane 15 feet. Along the High Level Sewer, south of the Thames, there is 6 feet of *débris* at Deptford, 3 feet at New Cross, from 2½ to 2 feet at Peckham, 2 feet at Camberwell, 2½ feet at the Plough Inn, Clapham Common. In Dulwich there is about 2 to 2½ feet, and in Wandsworth and Battersea ½ to 4½ feet (W. Whitaker).

On the average there is from 12 to 15 feet of "made ground" within the City of London, with a maximum of about 25 feet, and outside the City about 3 to 4 feet.

This is in accordance with the greater age of the City, and confirms the idea that the surface level of a town rises as the town grows older.

An area of about half a square mile in Fulham and another of about a quarter of a square mile in Battersea Park have lost alluvium without gaining an accumulation of waste, with the result that these areas are below high tide level.

Not only has Man deposited a mass of *débris* over the whole site of London, but he has disturbed the subsoil and frequently the rock below. In the construction of sewers, underground railways, wells, and the foundations of buildings, he has dug out considerable quantities of material, which has been carted away for the most part, although some has been used locally to fill up other excavations. The level of the underground water has been lowered considerably by pumping, also the atmosphere has been brought into contact with masses of buried strata, and is able to oxidise and hydrate them to a limited extent, as if they were at the surface. Moreover, tunnels generally require lining with brick, concrete, or metal, and in this way a great volume of man-made materials become buried in the natural rocks. The extent to which the strata under London have been excavated and the depth to which Man's disturbing influence penetrates is well illustrated by Gomme, who writes as follows: "People have little idea of what is built underground in London. Thus few streets have been more extensively utilised either above or below ground than that opposite the Mansion House. Immediately below the surface are the subways for gas and water-pipes; the house-drains and sewers are beneath these; at a still lower level is the railway, and below this again, the large low-level intercepting sewer. Between Lambeth Hill and New Earl Street the whole of the ground beneath the street is completely honeycombed with these several structures, which extend the

entire width of the street, from a depth of 30 feet below, up to within 18 inches of the surface. Few people passing along the street are aware of the network of iron pillars and girders which lie only a few inches beneath their feet. At Chatham Place, Blackfriars, are four large structures crossing each other in various directions below the surface; at the lowest depth, about 40 feet, is the low-level sewer, over which crosses the main Fleet Sewer, formerly a tributary stream of the Thames; above this, the Metropolitan District Railway; and above this again, the subway with its gas, water, and other pipes."

Sir Alexander Binnie, in giving evidence before the Water Commission, adduced the following instance of what underlies a London street: "The first instance is the Bayswater Road, between Notting Hill Gate and Westbourne Terrace. It is occupied by the main middle-level sewer of the London County Council, 6 feet by 4 feet; two 30-inch diameter, and one 21-inch diameter mains of the West Middlesex Company; two 30-inch diameter and one 18-inch diameter mains of the Grand Junction Company; one 36-inch main of the East London Company; then there are the local sewers and the large gas mains of the Gas Light and Coke Company; there is also an hydraulic company's main, about 6 or 7 inches in diameter; and below the whole of that there are two tunnels, 10 feet 6 inches in diameter, of the Central London Railway. At Notting Hill Gate the whole of these lines are crossed at right angles by the Metropolitan Railway."

The quantity of material excavated within the London area is very great. To form an estimate of the amount we must consider separately the quantities dug out of wells and boreholes in making sewers, underground railways and passages, and the foundations of buildings.

Wells and Boreholes.—Mr A. S. Foord has shown that no deep wells existed in or near the City of

London until, at earliest, the middle of the eighteenth century, although deep wells of great antiquity are known in many country castles. The old London wells were holes several feet in diameter with sides lined with stone or brick, wherever the strata were soft enough to require a lining. They were essentially reservoirs in which the water slowly collected. Frequently there was a boring at the bottom. With the fall in the water-level, due to pumping, and the growth of the desire for better water, wells and borings were made deeper and deeper.

An estimate of the quantity of soil and rock brought up from wells and borings within the boundary of London has been attempted from data supplied by Messrs G. Barrow and L. J. Wills in their book entitled "Records of London Wells." The authors give records of 901 wells and borings, all that they could find within the County. To arrive at the average amount of excavation represented by a single well, the volume of material dug out of 92 of the number, taken from different parts of the book, was calculated from the dimensions given, the average depth being 375 feet. From these data it appears that the approximate amount of material dug out of the 901 London wells and borings is 70,500 cubic yards, not considering the amount taken out of the headings often made in chalk in connection with the larger borings. As a rule the materials were left to accumulate round the site and became incorporated in the "made ground." The bulk of the material is derived from wide shallow wells; for although boreholes are numerous and deep, their diameters are so small (averaging about 8·9 inches) that they supply only about 5,000 cubic yards of the total. How many ancient wells have been lost sight of we cannot conjecture; but they would probably not add a great deal to the figures for the 901 known wells. The early wells, sunk in the days when the area covered by the

County of London was mostly agricultural land, would be shallow and comparatively few.

Sewers.—The total length of London sewers is not known; but generally a local sewer underlies each street, and in 1911 there were 2,200 miles of streets within the Administrative County of London. There are also sewers draining into the system from beyond the boundaries of the metropolis. In addition the Main Intercepting Sewers are 180½ miles, and the Stormwater Sewers 189½ miles long, according to Sir Maurice Fitzmaurice. Together these main sewers are about 370 miles long. Sir J. W. Bazalgette stated in 1865 that there were some 1,300 miles of sewers in London in addition to 82 miles of main intercepting sewers. He stated that, in the making of the latter, 3½ million cubic yards of earth was excavated. Assuming this rate of excavation per mile of sewer to hold for the additions made since 1865, we find that the formation of the 180½ miles of main intercepting sewers required the excavation of about 7,700,000 cubic yards of earth. If we include the stormwater sewers we shall probably not be far from the truth in estimating the total excavation from the main intercepting and stormwater sewers, 370 miles in all, at 14 million cubic yards. The 2,200 miles of local sewers will be referred to later (p. 168).

Underground Railways and Passages.—An estimate of the materials excavated during the construction of the Waterloo and City Railway, derived from data given by Mr Dalrymple Hay, shows that about 77,900 cubic yards was taken out of the tunnel, in addition to that removed from shafts and from widenings of the tunnel at stations. For the City and South London Railway, Mr J. H. Greathead gives similar figures, and also some data for other tunnels. The amount excavated at stations for the underground passages, lifts, and shafts has to be guessed at. It is here assumed that the diameter of each tube is doubled

at stations, and that each widening is 100 yards long. The volume taken out of the passages and shafts is regarded as equal to the extra amount dug out to make a single platform. On this reckoning the total excavation for all the London tube-railways (as distinct from the Metropolitan and District Railways) in existence in 1914, when the total length was 41·6 miles, amounts to 7,143,000 cubic yards, of which 3,300,000 cubic yards is the extra quantity allowed for stations, passages and shafts.

Mr B. Baker gives details of the Metropolitan and District Railways, from which we can form a rough estimate of the amount of excavation on those lines. On the Inner Circle, the part from Paddington to Moorgate was intended for broad gauge trains and is wider than the rest, being 28½ feet wide as against 25 feet for the remainder. Part was excavated by tunnelling, part was cut open from the surface, and for the present estimate the depth of this portion is taken as 25 feet, although some part of the cutting was made 42 feet deep. The 27 stations are assumed to be each 120 yards long, 56½ feet wide, and 25 feet deep. The length of the Inner Circle is 13 miles 8 chains, and from Mr Baker's data and the above assumptions we find that the total excavation was 4,119,000 cubic yards. This is probably too small because the extra depth of parts of the railway cuttings cannot be estimated for lack of data.

The excavation for the Greenwich Footway Tunnel is estimated at 12,590 cubic yards; for the Rotherhithe Tunnel, 201,377; and for the Blackwall Tunnel, 300,000 cubic yards.

Other Railways.—The *surplus* excavated material at the Great Central Railway terminus, i.e., for the double line from Canfield Gardens to Marylebone, a distance of two miles, was about 540,000 cubic yards, for that amount of material was deposited on the Neasden sidings, outside the County.

All the remaining railways within the City and County of London include $64\frac{3}{4}$ miles of tunnels and cuttings, as measured on the six-inch maps. Many of these railways have multiple tracks, such as those leading out of the great railway termini, and on this account they represent more excavation per mile than the Tubes and Inner Circle. Moreover, a tunnel requires less excavation than an open cutting, but on the other hand the railways hitherto considered include numerous stations, which involve extra excavation. In the absence of better data we shall estimate that on the $64\frac{3}{4}$ miles of railway cuttings and tunnels the excavation was at the same rate per mile as on the Metropolitan Railway, i.e., 314,427 cubic yards per mile. The total excavation will then be 20,359,000 cubic yards, and this is certainly too small a figure.

Local Drains, etc.—We cannot give an estimate of the amount of excavation involved in laying the 2,200 miles or more of local sewers, and the 5,382 (in 1914) miles of gas mains, and also the water-pipes, and in other street excavations. Owing to the thickness of " made ground," which we have seen averages from 12 to 15 feet within the City and about 3 or 4 feet within the County of London, some of the shallow excavations will be entirely in this deposit. The turning over of " made ground " affects it only inappreciably; the constituents will be more thoroughly mixed together and the fragments broken smaller, but that is all. Where the excavation goes through the " made ground," as may be seen almost daily when the streets are " up " for repairs to a drain, or for the foundation of a new building, the natural subsoil or rock becomes mixed up with the artificial soil. In the course of centuries this process adds to the thickness of " made ground," which may be expected to grow thicker, because foundations tend to be dug more deeply and drains to be laid at lower levels than formerly. Hence " made ground " increases not only by accretions of

débris from above but also by incorporation of the strata below.

Some account of the docks is given on p. 173. We have no estimate of the amount of excavation they represent, but we may include it with the minor street excavations and allow 3 million cubic yards for them all, a figure certainly too low. The Victoria, Albert, and Chelsea Embankments represent both excavation and accumulation, the latter predominating. The excavation is probably about 336,000 cubic yards (see p. 172).

Total Excavation.—Adding up the several items, we find the excavation within the City and County of London to be as follows:

	Cubic yards
From wells and borings	70,500
The Main Intercepting and Stormwater Sewers	14,000,000
The Tube Railways (to 1914)	7,143,000
The Inner Circle	4,119,000
The Great Central Railway, Marylebone to Canfield Gardens, surplus excavation	540,000
The remaining railways; cuttings and tunnels	20,359,000
The Greenwich Footway, the Rotherhithe and Blackwall Tunnels	513,967
The Victoria, Albert, and Chelsea Embankments	336,000
Docks, Drains, Foundations of Buildings, etc., at least	3,000,000
Total	50,081,467
say	50,000,000

Spread uniformly over the 116·9 square miles of the Administrative County of London, the average excavation would amount to about $3\frac{3}{4}$ inches. The excavations under London do not produce subsidence, as is the case with mining operations, because the ground is carefully supported by engineering structures. The underground excavations therefore are spaces filled with air or water. There may, however, be a small amount of subsidence due to the slipping

of gravelly foundations under weighty buildings, as is said to be the case at St Paul's, and also to the solution of chalk by the water pumped from borings.

The Thames.—In its natural condition the Thames was bordered, at what is now London, by extensive marshes. It is uncertain if there was a bridge over the river in Roman times, although one is mentioned by Claudius Cæsar, but Mr Belloc in his "Stane Street," gives reasons for thinking that there was. However, the first historical bridge at London was completed in 1016, and by 1209 a stone bridge had been built. For six hundred years this was the only bridge over the Thames at London, and it was rebuilt in 1810. Captain Burstal says that after the destruction of the old bridge several dredges were employed in the removal of gravel, of which, in the course of about twenty years, they removed a million cubic yards. These operations extended from London Bridge to Vauxhall, and subsequently further up the river. According to Mr Greaves, an immense quantity of ballast was dredged from the Thames in a promiscuous manner to ballast the Tyne colliers for their return journey. He considered (in 1877) that the material obtained for this purpose exceeded that dredged systematically since 1810. The hills of ballast may still be seen on the banks of the Tyne, though most have been removed recently, but large as they were, they represented only a part of the dredged mass, for great quantities were thrown into the sea on approaching the harbour mouth. The hollows left in the bed of the river would be subsequently filled by detritus swept down the Thames.

In the eighteenth century the river traffic was principally carried on by barges, some of which were as much as 200 tons burthen. At that time old London Bridge held up the water-level some $4\frac{1}{2}$ or 5 feet at low and $1\frac{1}{2}$ feet at high tide, and made the river

more readily navigable as far as Richmond. The stretch above Reading was also in fair condition, but between Richmond and Reading there was a series of obstructions. The draught of barges was limited to $3\frac{3}{4}$ feet with an inch latitude, but even then they could not pass shoals without flashes from numerous weirs and flash-locks. The water-mills at nearly all the locks used the water freely, so that the contents of several successive locks were frequently needed to lift the barge over a shoal. Sometimes eight weeks were occupied in a journey from London to Oxford, but traffic was considerable on the upper river, amounting in 1800 to 265,000 tons. In 1810 to 1814 powers were obtained to make locks in the lower part of the river, and six were soon constructed in the 15 miles between Penton Hook and Teddington. The new London Bridge offering less obstruction to the current than its predecessor, the water-level below Richmond was reduced, and the additional scour of the tide made it necessary to rebuild Blackfriars and Westminster bridges.

The Thames embankments are perhaps the largest engineering structures in London. The Victoria Embankment was made as part of the scheme for building intercepting sewers. Previously, however, the river had been embanked at the Houses of Parliament, at Greenwich Hospital, and at some other places, to a total length of 14,800 feet (nearly 3 miles), the earliest being made by Mylne, on the Middlesex shore, in 1767. Also private quays were made from Blackfriars Bridge to the West India Docks, and others on the south side, having a total length of 39,900 feet (nearly $7\frac{1}{4}$ miles), or about 10 miles in all. These embankments are comparatively modern; but there are some on the lower Thames of the making of which there is no record, although it is customary to attribute them to the Romans. They are about 100 miles long on the two sides of the river, and they

exclude tidal water from about 30 square miles of land, the surface of which lies 4 to 7 feet below Trinity Highwater Mark. Mr Redman thought that the lower reaches were embanked in the reign of Henry VI., and that before they were made the highwater at London probably did not exceed that at sea, whereas there is now 5 feet difference in tidal-level between Sheerness and London Bridge, a distance of 48 miles. This effect has been continued as far as Teddington, 19 miles from London Bridge, by the modern embankments. Mr Redman estimated that up to Teddington the tidal-level had been raised 4 inches by the Victoria and Albert Embankments. In the opinion of Mr Giles, however, the rise in level is due to the removal of old bridges that obstructed the tides, and to the effects of dredging.

The Victoria Embankment is about $1\frac{1}{4}$ miles long, and covers $37\frac{1}{4}$ acres of mud banks that have been reclaimed from the river. A subway carries gas- and water-pipes. Edwards (see Gomme) states that the embankment required 650,000 cubic feet of granite, 80,000 cubic yards of brickwork, 140,000 cubic yards of concrete, and 1,000,000 cubic yards of earth filling. There were also used 125,000 square feet (say 31,000 cubic feet) of York paving-stones and 50,000 square feet of broken granite (say 25,000 cubic feet of rolled granite road-metal); a total accumulation of 1,872,000 cubic yards of materials. The excavations amounted to 144,000 cubic yards.

The Albert Embankment is 4,300 feet long, and has its foundations 30 feet below Trinity Highwater Mark. These two, together with the Chelsea Embankment, are about $3\frac{1}{2}$ miles long, and have reclaimed about 52 acres of mud banks. We have figures for the Victoria Embankment only, but if the other two are similar in their proportions the three would represent an excavation of 336,000 cubic yards and an accumulated mass of bricks, stones, and earth of about

4⅓ million cubic yards. There are also the various quays mentioned above, for which we have no figures.

The first wet dock in London, and in fact in Britain, was the Greenland Dock at Rotherhithe. The Act authorising its construction was passed in 1696, and it was certainly in use in 1703. By 1800 another dock, known as Mr Berry's, was in existence. The West India Docks were begun in 1800, and the East India Docks in 1803, followed by the Surrey Canal Dock and the Commercial Dock. In 1828 St Katherine's Dock was opened, and there were then 200 acres of docks in London, an area not increased for many years. The accommodation for foreign trade consisted, for a long time, of a single quay, 400 feet long, extending down the river from London Bridge, and offering the same facilities in 1800 as in 1660.

In 1914 the Port of London docks covered 704 acres, with 29 miles of water-quays. These figures, however, include the new Albert Dock, now being made, and the Tilbury Dock, beyond the boundary of London. No estimate can be given of the total amount of excavation from the London docks. In the case of the south dock of the West India group the excavation was 1,600,000 cubic yards, and the material was deposited on land. The dock wall contains about 158,000 cubic yards of masonry, half being bricks and half concrete. In the original Victoria Docks the walls, including the face-walls and coping, were all made of concrete, of which 450,000 cubic yards were used.

The materials excavated from the London railways and sewers seem to have been disposed of, for the most part, by dumping them on the low marshy lands of Essex, down the Thames estuary, or into the sea; but this was not always done. The surplus from Marylebone Station and approaches was deposited at Neasden sidings, and the material from the Piccadilly

Tube at Hertford, in old ballast-pits. At this town the gravel of the River Lea has been dredged on an extensive scale, leaving considerable pools, and the Tube waste has been used to fill the ponds and restore the original ground-level. A geologist who did not know this would be puzzled by the presence of London clay with fine crystals of selenite where he would expect to find a river gravel.

A very different form of denudation is effected by solution of rock. This question is treated in Chapter VIII (p. 277), but here we may mention that the Metropolitan Water Board draw more than $5\frac{1}{2}$ million gallons of water daily from chalk below the County of London, and there are also private wells obtaining water from the same area. A million gallons of water pumped from the chalk is said to contain $1\frac{1}{4}$ tons of chalk in solution, occupying 17·6 cubic feet. The Water Board therefore alone remove 96·8 cubic feet of rock daily from beneath London, or 1,306 cubic yards per annum.

A considerable amount of building-stone is destroyed in London by solution. Rain carrying carbonic and sulphuric acids, the latter derived from the burning of coal and the former from the same source and from animal respiration, has solvent powers on limestone and some other rocks. The chief building-stones of London are limestones, and these perish rapidly, while the mortar between bricks requires periodical replacement. The London atmosphere seems to have improved of late years, for the notorious London fogs are now rare events; but the rain is probably as much charged with acid as ever it was, although freer from soot. The extent to which building-stones decay is strikingly shown by an exhibit in the Museum of Practical Geology, in Jermyn Street. This is a limestone statue taken from the outside of St Paul's Cathedral and showing marked furrows. At the top of the head of the figure is a lump of lead

projecting an inch, but which was originally level with the surface of the stone.

While carbonic acid dissolves the stone and removes it in solution in rain-water the sulphuric acid forms gypsum (sulphate of calcium), a substance only moderately soluble. This is the reason for one of the characteristics of London scenery, namely the sharp alternations of black and white seen on many public buildings. The black patches represent a deposit of soot, while the white areas are parts that have been more exposed to the rain, so that the soot is washed off. The whiteness is due to the formation of sulphate of calcium.

Calcareous sandstones also are liable to decay, the stone being left in a powdery condition by the solution of the cementing material. Even igneous rocks do not escape. The so-called Norwegian "granite," for example, becomes spotted with rusty stains caused by the oxidation of the iron present in the rock.

Prevention of Natural Erosion.—Although Man has been an active agent of denudation in London, he has greatly hampered natural denudation. The greater part of London is protected by pavements and roofs from the action of atmospheric agents such as frost and rain. Even in open spaces there is often an accumulation of "made ground" protecting the natural surface below. The rain that falls on London runs off the protected surface into sewers and so into the Thames; whereas before London was built the rain was collected by streams, and these were able to denude their channels in the usual manner. Even in the case of gardens and parks erosion must at present be very slight; for the open spaces are too small to enable the water to collect into streams, and erosion will be reduced to little more than solution by rain-water, and the removal of a little soil into the sewers.

Accumulation.—Having now considered the quantities of rock removed from London we have to

find out what additions have been made to the county. In the early history of London there is scarcely any mention of engineering feats of importance; sewers, railways, boreholes, are all of them modern innovations.

In the Middle Ages a burgess's house was a wooden framework with interstices filled with plaster and a roof thatched with straw or reeds. The natural result was that devastating fires were frequent. In the first year of Stephen's reign (1135), a great fire destroyed St Paul's and raged from London Bridge to St Clement Danes. One consequence was that in 1189 an Assize of Building was drawn up, ordering citizens to build houses with party walls of stone up to a height of 16 feet, but this order seems to have had little effect and, in 1212, a new ordinance following another severe fire ordered new houses to be covered with tiles, single boards, or lead, instead of thatch. Until long after this period stone houses were so few that they were used as direction marks, much as we now speak of The Elephant and Castle or The Angel, Islington. Between 1350 and 1450 a marked improvement in wealth led to the erection of houses of two or three storeys. In the reign of Richard I., windows were mere apertures. Glass was only used by the most opulent and is first mentioned as a regular import in the reign of Henry III. London was nevertheless much in advance of continental cities in comfort and cleanliness. At the end of the twelfth century the population was estimated by Peter of Blois at 40,000; Hallam put the population in John's reign at between 30,000 and 40,000 and in 1377 a poll-tax gave it as 44,700.

The old inhabitants of London, Westminster, and the country villages now absorbed into London County, accumulated a mass of *débris* round their houses. Ordinary house and trade waste was dumped in the nearest available place, not uncommonly the public road. There are many complaints in old town records of streets becoming impassable owing to the accumula-

tion of rubbish thrown out of the houses. For example, in the prosperous borough of Nottingham, the streets, about the fifteenth century, were blocked with piles of cinders cast out smoking hot from the bell foundry and the iron workshops, and with heaps of corn which the householders winnowed by throwing it from an upper window. Again, the important city of Norwich had its market-place still unpaved in 1507, but a judicious order was issued that no one should dig sandholes there without the Mayor's licence.

Household and other refuse, then, was trodden down in the streets and gradually raised the ground-level under the town, the bulk being added to by the ashes of buildings destroyed in the fires. Outside the town a certain amount of digging for sand, clay, and gravel took place, and as the town grew, these pits were filled with rubbish and built over. Also, as we have seen, the stream-beds, such as the Wallbrook, became filled up with refuse.

Sewers were originally intended to replace natural streams and carry off the rainfall, and in London up to 1815 it was a penal offence to discharge sewage into sewers. Later, from 1815 to 1847, it was permissible, and after 1847 it was compulsory to do so. During the six years 1847-53 some 30,000 cesspools had been abolished and the drainage turned into the Thames. The pollution of the Thames became such an insufferable nuisance that at last, between 1856 and 1874, intercepting sewers were built, on both sides of the river, to carry the sewage to Barking and Crossness, respectively 11 and 13 miles below London Bridge. Large reservoirs were built to contain the sewage so that it need only be discharged at ebb tide. Up to 1890, crude sewage was discharged into the estuary, but since that date it is precipitated by chemicals, and the sludge carried down the river in vessels for 55 miles, and deposited over a distance of 8 to 10 miles in the Black Deep. In the year 1913-14 the sewage treated

was 104,567 million gallons, which required 19,702 tons of lime and 5,009 tons of ferrous sulphate. The sludge produced and sent to sea weighed 2,660,000 tons, containing 204,634 tons of solid matter, or 7·69% of the sludge.

In 1911-12 the house and trade refuse collected within the County totalled 994,916 tons. As the trade refuse from Westminster and part of Paddington are not included, we may take the round figure of 1,000,000 tons for the whole of London.

Street sweepings consist of *débris* from the pavements, iron from horses' hoofs, horse-dung, etc. With the rapid replacement of horses by motors the sweepings change their character, the tendency being probably to diminish the bulk by the loss of much organic matter. In 1867 Dr Lettenby analysed the sweepings from a London stone paved street and found that it contained, on the average, 47·2% of organic and 52·8% of inorganic matter. Conditions have changed greatly since 1867. The loss of organic matter through the replacement of horses by motors is more or less counterbalanced by the growing use of wood and asphalt-pavements. Mud from a wood pavement contains about 60% of organic matter.

The ways of disposing of house, trade, and street refuse are diverse and new plans were constantly being adopted. Formerly it was customary to dump the refuse on waste lands, but this created a nuisance and is rapidly falling into desuetude. To mention two instances only, the large gravel-pits at Wheathamstead and at "The Twentieth Mile" near Hatfield, in Hertfordshire, are largely filled up with London rubbish brought out by train, the trucks being loaded with gravel and sand for the return journey. A goods-train came to Wheathampstead daily, loaded with waste to be deposited in the old workings. This has now been stopped for three or four years, owing to the nuisance it created, but some 75,000 square yards (15½ acres) of

land were filled up level with the general surface to a depth of about 20 feet. In the case of the Twentieth Mill Pit, an area of about 56,000 square yards (11½ acres) has been filled up to a similar depth. In time, weeds, chiefly nettles, grow over the waste and sooner or later the organic matter will be decomposed and destroyed, leaving the mineral matter, consisting of coal cinders and ashes, bits of crockery, tin-cans, fragments of metal, slate, etc., etc. The atmospheric agents will turn the iron into ferric hydrate, which we may expect will form a cement to the more stable fragments, the final result being a breccia cemented by ferric hydrate, a kind of iron-pan. The ground, of course, will sink greatly as the organic matter decays. If we consider the proportion of clinker produced by a refuse-destructor we may expect about 70% to disappear and 30% to remain permanently.

The Cities of London and Westminster send all their street-sweepings in barges down the Thames and dump them on the marshes bordering the estuary. There the rubbish helps to raise the ground-level above tidal waters. However, street-sweeping has been reduced to a minimum by efficient flushing of the streets, and most of the refuse now passes into the sewers.

Readers of Dickens will remember the story of the Golden Dustman in "Our Mutual Friend." The following quotation, from Pink's "History of Clerkenwell" (p. 501), records the remarkable use made of a rubbish heap similar to, if not identical with, the one described by Dickens.

"Early in the present century (nineteenth) the spot of ground on which now stand Argyle Street, Liverpool Street, Manchester Street, and the corner of Greys Inn Road, was covered with a mountain of filth and cinders, the accumulation of many years, and which afforded food for hundreds of pigs. The Russians bought the whole of the ash-heap and

shipped it to Moscow, for the purpose of rebuilding that city after it had been burned by the French."

House refuse contains garbage, bits of leather, metal, pottery, and an endless variety of odds and ends, and also cinders and ashes from the grates. Until recently the refuse was largely in demand for the making of stock-bricks, in which it used to be an essential ingredient. Of late years, however, destructors have been put to deal with the waste as a whole, and the stock-brick trade was gravely threatened until it discovered a substitute (see p. 183).

In the ways of disposing of waste matters there are endless variations. Southwark pulverises the house-waste to the condition of flock and can then sell it as a manure, but the demand is not large. At Leyton the sludge precipitated from sewage is pressed into cakes and mixed with the house refuse in the proportion of two parts of sewage-cake to one part of dust, and the mixture burned in a destructor. At Ealing the sludge and the house refuse are mixed together and burnt. The residue from a destructor is clinker, about 25% by bulk and from 25 to 33% by weight of the original waste. Clinkers vary greatly in character. In some cases the rough lumps are used for " hard-core " (i.e., as a foundation for roads), in other cases the clinker is cast into paving-stones, which are eventually ground to powder under the traffic.

Beneath a large town the " made ground " tends to level up not only the natural hollows but also the excavations made by previous generations. The clay, sand, or gravel dug out in olden times for bricks, mortar, pavements, etc., has been used on the spot, for there was little transport before railways were built, and the worn out *débris* therefore remains in the " made ground " not far from the place from which the raw materials were taken. The thickness of " made ground " is roughly proportional to the age of the

town, as is well shown by London. Under the ancient city we find the greatest thickness and a diminution as we pass from the centre, with local thickenings where towns and villages were long established before they were absorbed into the metropolis.

All materials brought into London through the centuries contributed their quota to the "made ground." For example, the ashes of coal and wood fires have accumulated there for more than six hundred years. Fortunately there are statistics of the quantity of coal brought into London at intervals from 1600 onwards. From 1776 to 1813, 1820 to 1889, and 1903 to 1912 we have annual figures. By plotting a curve it is possible to fill in the gaps in the statistics, and the result is that during the three hundred and twelve years from 1601 to 1912, inclusive, the coal brought into London amounted to about 846 million tons, or say that 850 million tons have been brought in since the earliest times. Suppose the ash to average only 5% of the coal, it would amount to 42½ million tons, besides much half-burnt coal. The proportion of the latter to ash has diminished of late years, as is mentioned in the account of stock-bricks (see p. 184).

The following figures illustrate the rate at which the amount of coal brought into London has increased. Up to 1800 the figures are by T. Wiltshire, from 1823 to 1889 from the Mineral Statistics, and from 1900 to 1912 from London Statistics.

1600	amount	200,000	tons
1650	,,	240,000	,,
1700	,,	428,000	,,
1750	,,	700,000	,,
1800	,,	1,099,000	,,
1850	,,	3,638,883	,,
1875	,,	8,204,893	,,
1889	,,	12,650,726	,,
1903	,,	15,987,787	,,
1912	,,	16,083,198	,,

In considering the figures we must remember that the area to which they apply has varied. It is probable, however, that in the earliest records villages and towns near the London of those days, such as Fulham, Greenwich, or Tottenham, are included in the supply received by London, for coal was sent from Newcastle by ship, and London would naturally supply the adjacent country. The area covered by the earlier statistics may therefore be not very different from that to which the figures for 1903 to 1912 apply, namely, to Greater London, comprising the City and County Police Districts, with an area of 692·9 square miles. The coal ashes therefore have been deposited over an area considerably larger than the City and County of London. Nevertheless, remembering how the population has spread outwards from the City, concurrently with the increase in the coal brought in, it is clear that the greater amount of coal used has been in the central area, and that next in importance as users of coal came the towns and villages near by (now absorbed into the metropolis), next the towns and villages further out, such as Hatfield and Richmond, and finally, the country areas in between.

Some coal brought into London has been reshipped, but the proportion is not large, and we have purposely taken a low estimate of the coal brought in before 1600, and of the percentage of ash, to offset this factor.

It seems a safe assumption that the ashes were disposed of locally, and became, sooner or later, part of the "made ground." Some of the ashes were incorporated with the "made ground" directly, as mentioned before (p. 177), but for at least a century ashes, cinders, and other household refuse have been taken in barges, either up or down the river, to be made into stock-bricks. The bricks were used in London buildings; and when, in course of time, these were destroyed, the broken bricks containing the

ashes became part of the " made ground." Probably little coal was used in the country districts, because, until recently, the scattered population needed little fuel except wood. The refuse from scattered houses would find its way into the fields and be ploughed into the soil.

All organic substances, such as food, leather, or wool, contain a proportion of inorganic ash, and after decay the ash is left in the soil (or clinker, if put into a destructor) while the volatile ingredients return to the atmosphere. The soluble parts of the ash will be washed by rain into the rivers; the insoluble parts remain behind permanently.

The numerous fires that have devastated London through the centuries must have added a large amount of ashy material to the " made ground." Refuse destructors are a comparatively modern innovation, and even now probably not more than half of the waste products of the city are burnt in them.

We must also remember that before 1815 the sewage was entirely, and until 1847 partly, retained in cesspits. According to Henry Jephson, in 1841 there were 270,000 houses in London, most of which had cesspools beneath, while a large number had two, three, or four. Some of them were so large as to be called " cess-lakes." Parts of West London were literally honeycombed with them. Hundreds, even thousands, had no drainage whatever, but the greater number overflowed. Further, Jephson, in 1907, quotes Mr Cholwick as saying that 50,000 persons are buried annually in spaces not exceeding 203 acres in the aggregate.

Masonry in London—Stock-bricks.—Until about 1885 the only type of brick used in London was the stock-brick, while on the other hand this brick was scarcely used elsewhere. The chief centres of the industry are at Sittingbourne and between Southall and Slough. The waste from London's dustbins was

sent in barges by river and canal, and stacked on waste ground for a time, until much of the organic matter had decayed, which greatly diminished its bulk. The residue was then screened and sifted to separate the fine ashes from the " breeze " (small cinders). In the spring an 18-inch layer of the fine siftings (called " soil ") was spread over 6 feet of clay and chalk, and the whole thoroughly mixed and made into bricks. Before burning, the composition of the brick is " earth " (clay and " soil " mixed) 81, chalk 13½, and carbon 5. The " breeze " was used to start the kilns, but most of the heat was produced by the slow combustion of the " soil," which contains about 37% of carbon. A thousand bricks required 7 cwts. of " soil " and 3 cwts. of " breeze," while a ton of refuse contains 3 cwts. of breeze, 10 cwts. " soil," and 7 cwts. large refuse (" hardcore "), consisting of all manner of articles, ironware predominating, but to a large extent organic. The " hardcore " accumulated in vast quantities, and was frequently used to fill up the clay-pits. The iron and organic matters oxidise, the slow decay taking years, and the bulk diminishes. Occasionally a dump took fire and smouldered until all combustibles were burnt out, incidentally creating a considerable nuisance. When the clay was very strong as much as 33% of sweepings from macadamised roads (called " mac ") was added to serve as sand. For a century the mode of manufacture remained unaltered. After about 1870 a deterioration in the quality of " soil " set in, due, in part, to the decrease in the proportion of ashes to other refuse, in consequence of improved housekeeping; but in part to a deterioration in the quality of house coal. In 1899 complaint was made that the value of " soil " had gone down 7% during the previous twenty years, apart from the increased proportion of large and useless refuse. Moreover, the London vestries began to put up refuse destructors and burn their waste. Finally

people living near the brick-fields became more fastidious and complained of the smell of the decaying refuse. As a result the stock-brick trade was threatened with extinction, until coal-dust and coke "breeze" were tried and proved to be better than the refuse, only $2\frac{1}{2}$ cwts. of coal-dust being needed per 1,000 bricks instead of 7 cwts. of "soil."

So long has this industry been carried on that brick-earth has been nearly worked out as far up the Thames as Windsor. Originally brick-earth covered the Thames gravels to a depth of 4 or 5 feet, and this has been removed nearly everywhere. Nowadays London clay with chalk added is used for the bricks. In 1854 the production of stock-bricks in the London area was 130 millions, and in 1899 about 500 millions, the latter number requiring about 2 million cubic yards of clay and chalk.

Mr A. L. Leach has given an account of a chalk mine at Wickham, Kent, that yielded 100,000 tons of chalk, between 1853 and 1903, for use in the manufacture of stock-bricks. There is a shaft about 80 feet deep, and the chalk was worked in galleries supported by large pillars.

Stock-bricks have no longer a practical monopoly of the London market. The Fletton (Peterborough) bricks are now supplied in immense numbers to the metropolis. However, the Peterborough brick-trade only commenced about 1887, and up to, say, 1890 the stock-brick supplied London almost exclusively.

Almost all the household refuse of the metropolis remained in the area, being either directly trodden into the ground, deposited in old pits, or absorbed into stock-bricks that were used up locally.

Bulk of Brickwork in London.—The number of dwelling-houses in the Administrative County of London in 1911, according to the Census, was 606,271, and 1,583 more were being built. Other buildings comprised 2,030 places of worship; 68 government and

municipal buildings; 275 theatres and other places of amusement; 20,330 shops; 4,381 offices; 18,090 warehouses, workshops, and factories. A very great majority of the houses are of brick, and London houses are larger on the average than those of other parts of the country, for in London even working-men live in large houses. If we allow 25,000 bricks per house and offset any stone houses by the other 45,000 buildings in London, many of which are of brick, we find that in 1911 London buildings contained about 15,196 million bricks. The main sewers contain about 700 million bricks, and in addition there are the millions employed in lining the railway tunnels and cuttings. The main sewers contain also about 1,937,000 cubic yards of concrete.

The number of bricks in existing buildings, tunnels, etc., in the County of London will certainly exceed 17,000 millions, and, reckoning 395 bricks to a cubic yard, this represents $45\frac{1}{3}$ million cubic yards of brickwork, or sufficient to cover $14\frac{1}{2}$ square miles to a depth of one yard. Spread uniformly over the Administrative County of London, which has an area of 116·9 square miles, the brickwork would form a layer of $4\frac{1}{2}$ inches.

The ancient buildings of London, with few exceptions, have been destroyed, and the fragments remain for the most part in the "made ground." By taking the number of houses at different dates and allowing for the average life, it would be possible to estimate roughly the amount of broken masonry now incorporated in "made ground." It would, however, be very difficult, and the same result can be obtained by estimating the bulk of made ground (as has been done above) and finding its average composition. This latter investigation remains to be carried out. In estimating ancient masonry we have to remember the closer packing of buildings in the older days. So late as 1850 it was permissible to build on spaces at the

backs of houses, and so great heaps of buildings existed, absolutely covering the ground, back to back and side to side, so long as one could be fitted in. This packing led to more frequent and more disastrous fires and so diminished the average life of buildings. On the other hand, modern buildings contain more masonry than the older ones, as they are on the whole more massive and higher, and this compensates for the open spaces between them.

Population of London.—The population of London appears to have fallen off considerably after the Romans retired from Britain. The following table from C. Crichton gives the population at different dates:

1348-49	under 50,000
1377	43,700
1400-1500	40,000-50,000
1532-1535	62,400
1563	93,276
1580	123,034
1593-1595	152,487
1605	224,275
1622	272,207
1634	339,824
1661	460,000
1682	669,000
18th century	about 700,000
1801 (Census Returns)	958,863
1871 ,,	3,251,913
1914 ,,	7,251,402

The population in 1914 is of Greater London, i.e., the Metropolitan and City Police Districts.

It must be remembered that the area of London was growing and therefore the density of population at any date is not obtainable from the figures. The density of population and the density of masonry have not a constant ratio. In early times people were satisfied, as already stated, with small houses built close together and consisting in part of timber. Later on these flimsy

erections gave place to more solidly constructed buildings, but these were still packed closely together. The size of buildings and density of population both increased for a considerable period; but with the introduction of better means of transport and improved ideas of hygiene the population began to spread over a larger area. This period may be regarded as beginning with the Victorian era. The area of London then commenced to increase rapidly, as the population both increased in size and felt the centrifugal force. In Central London the population began to diminish, but the size of structures tended to increase as more and more massive public and commercial buildings replaced the older ones. Here, then, the density of population was diminishing while the density of masonry, i.e., the bulk on a given area, continued to increase.

We have few data relating to the number of houses in London at different times. In the reign of James I., when the population was about 150,000, the number of houses was about 17,000, and these were for the most part built of brick below and timber above. In 1836 Mammatt estimated that there were 400,000 houses in London. "London Statistics" gives the dwelling houses in 1911, including those under construction, as 607,854, besides other buildings.

The point of these remarks is to show the difficulty of estimating the rate of accumulation of artificial materials over London. The rate increases with density of population and also with the increased size of buildings and these factors sometimes work in opposition locally, although in the broad view population and buildings both tend to increase. Another factor is the length of leases, for in busy centres it is usual to pull down a building when the lease expires and construct a more massive one on the site; incidentally causing a large amount of masonry to be added to the *débris*.

London has now been described in some detail from

the human geological aspect. One or two points remain to be mentioned. There has been a certain amount of denudation due to the cutting of roads; especially in the hilly region around Highgate and Hampstead, but not to a great extent, for on the whole London rests on flattish ground. Moreover, any cuttings now made would be to a considerable extent in " made ground." The temperature of London has become warmer by several degrees in consequence of the heat generated by man and other animals, and by the burning of fuel. Doubtless the drainage of the old marshes has had a similar effect.

The geological activities of Man on the site of London are similar to those on the site of any village or town; though there are differences in detail. Only in the largest cities are there underground railways or deep-seated main sewers. But the growth in elevation of each centre of population on its own *débris* is the outstanding feature. Exploration of ancient cities in various parts of the earth has shown that on the average they deposit a foot of *débris* per century, and this agrees with what we know of London. It would be interesting to check the figure in various British towns. In mining centres subsidence may neutralise elevation due to accumulation, but the formation of " made ground " takes place just the same.

CHAPTER VI

ACCUMULATION

After considering Man's destructive activities on the Earth's crust we naturally proceed to consider his creative or preservative activities.[1]

It may seem absurd at first sight to speak of rocks made by Man; yet if we remember that to the geologist a rock is any solid substance that enters into the composition of the crust of the earth, we see that many artificial things, such as embankments, colliery dumps, or masses of brickwork, come under this definition.

Rocks are divided by geologists into four classes, as follows:

1. *Igneous*. Rocks that have been melted, e.g., granite, lava, trap-rocks.
2. *Clastic*. Composed of fragments of previously existing rocks or minerals, usually, but not always, sorted by water; e.g., sandstone, clay, some limestones, morainic material, volcanic ashes. Also *Æolian*, a small class of rocks produced by wind-action, e.g., sand-dunes.
3. *Metamorphic*. Rocks belonging originally to other classes but subsequently altered greatly by heat, pressure, or water-vapour, or by all of these agents. They have undergone radical chemical and physical changes; e.g., gneiss, and schists of various kinds.

[1] The preservation of the sea-coast is described in the next chapter.

4. *Chemically formed.* Formed as the name implies, e.g., some limestones, gypsum, rock-salt.

Man-made rocks can be classified into the above four groups.

1. Examples are: Glass, slags, metals.

Glass and slag are similar to the volcanic rocks (i.e., igneous rocks poured out by volcanoes) called obsidian and pitchstone. The resemblance is often very close, and a fragment of black bottle-glass is practically identical in appearance and microscopic structure with obsidian. Slags are more like pitch-stones, showing under the microscope incipient crystalline structure. The vesicular character of slag can be closely matched amongst lavas, notably in pumice-stone.

The remarkable structure called pillow-structure, found in a certain kind of lava (spilites), is seen in the slag from the blast-furnaces of Middlesbrough. The glowing slag is conveyed in wagons to the tip-heap, where it is sent rolling down the slope in a fiery stream. On examining the tip it is found to be made of blocks having the outward shape of the wagons in which they were carried. An outer layer some inches thick is chilled, during the transit, and forms a rind of solid slag enclosing a highly vesicular mass resembling pumice. Frequently while rolling down the slope of the tip the blocks have burst, and the fluid interior has flowed out, leaving the hollow shell. These features are found in the Carboniferous and Devonian lavas of the Brent Tor district in Devon. Of course the lava blocks have not the shape of wagons, but the rock is made up of large sub-spherical masses having a chilled margin or rind, enclosing a vesicular mass. The lava was poured out under the sea, and on coming into contact with the water the surface was chilled. Driven on by the molten stream behind, and rolling over the sea-floor, the rounded masses called pillows were formed.

Frequently they burst and the shattered rind became surrounded by the viscous matrix forming a kind of false breccia. Here there is a close similarity between slag and lava, and the study of the former throws light on the origin of pillow-structure.

Igneous rocks may be divided into four groups according to the amount of silica they contain. The groups are: (1) Acid, with from 66 to 80% of silica; (2) Intermediate, with from 55 to 66% of silica; (3) Basic, with 40 to 55%; and (4) Ultrabasic, with less than 40% of silica. Each of these groups is divided into (1) Volcanic, (2) Hypabyssal, (3) Plutonic, according as the rock was (1) erupted at the surface; (2) formed as dykes, sills, or laccolites, at a moderate depth below the surface; (3) cooled very slowly in great masses and deep down in the earth's crust. In consequence of their mode of formation, volcanic rocks are glassy or partly crystalline; hypabyssal rocks are crystalline but have a fine-grained texture and frequently contain large crystals in a matrix of fine materials; plutonic rocks have cooled very slowly under great pressure and therefore have usually a coarse-grained texture.

There do not seem to be any artificial representatives of the coarse-grained igneous rocks of deep-seated origin, such as granite.

Apart from the existence of such rare substances as native gold, platinum, copper and mercury, the metals do not occur uncombined in Nature. Native iron exists as a mineralogical curiosity, chiefly, if not entirely, in meteorites, but the production of millions of tons of iron, steel, copper, lead, zinc, brass, and other metals, is one of the greatest works of Man. Just as a mass of meteoric iron would be classed as a rock, so we may also regard these metallic masses as rocks, and, since they are produced by smelting in furnaces, at great temperatures, they would fall into the igneous division. Also they belong to the ultrabasic group.

2. *Clastic.* Examples are: "Made ground," concrete.

"Made ground" is a varied mass consisting of human exuviæ of every conceivable kind, mixed with more or less of soil or rock. In one place it may be entirely composed of fragments of manufactured articles, at another purely of natural rock. In the latter case its artificial character may not be at once realised, e.g., the material excavated from a well, spread out and overgrown with vegetation. But even though it has every appearance of being a natural formation, it differs from it in the very important character of being out of its natural place, not only as a whole but in the relative position of its parts. Parts of different strata have been mixed together, and the whole has been moved, in the particular case mentioned, against gravitation.

As natural deposits in some ways analogous, we may instance parts of the Glacial Drift, which consists, as a rule, of a mass of materials of varied size and origin, as in the case of made ground. Both deposits may have been moved great distances, or made of local materials. A mass of rock may be torn up by ice, and its ingredients mixed together without leaving any obvious sign of disturbance, as, for example, in Middlesex, where, in some places, Glacial Drift is composed of transported London clay, and since it rests on solid London clay, it is not always separable from the undisturbed strata below. Such a state of affairs is similar to cases in which Man has turned over the ground without introducing any foreign element to call attention to the disturbance. In other cases the materials of the Glacial Drift are derived from afar, and exhibit a marked contrast to the rock on which they rest.

"Made ground" may be a flat deposit, relatively thin, or it may be heaped into mounds, in which form it sometimes resembles the moraines, kames, or eskers

left by glaciers. In other cases it forms terraces in valleys, when it resembles in shape the gravel-terraces left by rivers. Instances of such terraces may be seen on the outskirts of Sheffield, where some of them are now cultivated as allotments.

Æolian. Examples of artificial æolian rocks are comparatively few. Where the waste products of some industry are in a state of fine division and come under the action of wind, they are formed into dunes similar to those of the seashore. Perhaps the best illustration is the sand derived from the finely powdered banket of Johannesberg. After the gold has been extracted the tailings are dumped near by, and under the action of wind are re-arranged into dunes.

If material churned up by Man, instead of being deposited on land, finds its way into a sea, river, or lake, whether by accident or design, it is sorted and spread out by water and forms a sedimentary rock whose human origin is only shown by the nature of the constituent fragments, or not at all if no fragments of extraneous substances have been introduced. Yet without human action the clay or sand-bank formed would never have existed. Here the boundary between artificial and natural rock is breaking down, as always happens when we attempt to put natural processes and things into classes. From these remarks it appears that artificial clastic rocks can be divided into three groups:

(*a*) Those petrographically unlike anything in Nature, e.g., the waste from a chemical works.

(*b*) Those differing petrographically from naturally formed rocks in minor points only, such as (1) the state of attrition of the particles, e.g., the mounds of sand that has been used for polishing glass; or (2) in the admixture of particles of artificial origin with ordinary sand

or clay, e.g., glass-dust in the mounds of sand just mentioned; or (3) in the presence of an occasional relic of Man, such as a fragment of pottery, which in a natural rock would correspond to a fossil.

(*c*) Rocks apparently entirely natural, yet owing their formation to human activities, e.g., masses of silt deposited through an artificial change in the position of a current of water.

3. *Metamorphic.* Examples: Brick, porcelain, cements, distilled oil-shale.

In the manufacture of bricks the clay from which they are made is heated to a temperature more or less high according to the kind of goods required. For refractory bricks intended to line furnaces the temperature required in the kiln may be as much as 1,200°C. In the case of common brick a much lower temperature is used, for not only is it unnecessary to expose them to such great heat, but the clays of which they are usually made would fuse at the temperature used for the more refractory clays, and the resulting product would be a slag and not a brick. In the case of vitreous bricks a kiln-temperature just short of fusion point is chosen. The chemical and mineralogical changes that occur in the clays treated in the kiln are very similar to those undergone by a clay during its metamorphosis by an igneous rock. We may therefore regard bricks, tiles, terra cotta, earthenware and porcelain as metamorphic rocks. Portland cement is similar to a metamorphosed, argillaceous limestone, and it, together with other cements and mortars, may be put in the metamorphic division. The shale from which paraffin has been distilled may also be placed here.

All these artificial products are similar to thermo-metamorphic rocks, i.e., rocks altered by the heat and vapours generated by igneous intrusions. The other

division, the dynamic metamorphic rocks, such as schists and gneiss, formed by earth-movements on a large scale, do not seem to have any artificial representatives.

4. *Chemically Formed.* Examples: Waste from various chemical works and from water-softening processes.

Here we may place such materials as the heaps of finely divided calcium carbonate precipitated from drinking-water by Clarke's water-softening process, and the heaps of calcium carbonate from the ammonia-soda process for making caustic soda and sodium carbonates. The chemical substances manufactured may themselves be regarded as man-made rocks or minerals.

A vast number of substances made by Man are never found in Nature. Not only are there the organic compounds produced in the laboratory,[1] which are strictly comparable to native minerals such as ozokerite, asphalt, or copal, but there are also inorganic substances which differ from minerals only in the fact that they owe their existence to the chemist instead of to Nature. An interesting case is that of ferrous sulphide, which is a common reagent in the chemical laboratory, but in Nature is only known from meteorites.

A question will arise in many minds: do any of the products of human activities occur in sufficient quantity to be compared with masses of rock? The answer is that they do: the "made ground" on which a large town stands is of the same order of magnitude as a seam of coal, a stream of lava, or a marine beach. So also are the tip-heaps of many colliery districts or the slag-deposits of an iron-making centre. In other cases the artificial product is disseminated in small quantities,

[1] Of over 150,000 organic compounds now known to science, the vast majority have been made by the chemist and are never found in Nature.

which, if brought together, would make up a very considerable mass. Take the case of glass for example; hundreds of millions of tons have been made, but have been scattered over the earth in the form of small articles.

Some notes will now be given on various artificial "rocks."

Glass.—Plate glass was made in South Shields in the early part of the seventeenth century, but it was first cast on a table in 1771, in Lancashire. The output of the United Kingdom in 1836 did not exceed 7,000 square feet weekly, but the abolition of the tax on glass in 1845 soon caused the output to rise to 140,000 square feet per week, and this in spite of large imports. In 1854 the output was three million square feet of polished plate weighing 5,500 tons, and 2,240,000 square feet of rough plate (introduced about 1852) weighing 2,000 tons.

In this country, the first works of any importance making crown glass was at Newcastle and was founded about the middle of the seventeenth century. Until 1832, when sheet glass was first imported from France, crown glass was used for all important buildings, but sheet glass caused it to decline in favour. The output of crown and sheet glass together, in 1844, was 6,700 tons, but the outputs of both varieties increased greatly after the tax was dropped, and, in 1854, the British output of the two kinds amounted to 35,500,000 square feet, weighing 15,000 tons, whilst in 1866 it had risen to about 22,000 tons. This last mentioned quantity required for its manufacture approximately, 13,300 tons of sand, 6,000 tons of carbonate of soda, 12,000 tons of limestone including chalk, together with 220,000 tons of coal as fuel. Carbonate of soda instead of seaweed ashes began to be used in 1830; the carbonate has now been replaced by sulphate of soda. A by-product of the glass industry is sulphuric acid, produced by the reaction of sand and sodium sulphate

in the furnace. At one time the acid escaped into the air, with disastrous effects on crops, mortar, and buildings, especially those made of limestone.

The composition of some glasses is as follows:

Parts of	French Plate	Windsor	Lead Flint	Bottle Glass	Bohemian
SiO_2	100	100	100	100	100
Na_2CO_3	34	5	—	—	—
Na_2SO_4	—	37·5	—	25	—
$CaCO_3$	14·5	35·8	—	34	—
CaO	—	—	—	—	18
K_2CO_3	—	—	20	—	40
MnO_2	.25	·4	—	—	—
Pb_3O_4	—	—	60	—	—
Coke	—	4	—	3	—
Slag	—	—	—	5	—

Glasses are mixed silicates. A soda-lime glass approaches the formula $Na_2O,CaO,6SiO_2$, and a lead-glass $K_2O,PbO,6SiO_2$; but the latter varies so much that it may become $5K_2O,7PbO,36SiO_2$. The soda-lime glass differs in composition from the mineral albite (soda-felspar, which is $Na_2O,Al_2O_3,6SiO_2$) in containing calcium instead of aluminium.

The window-glass used in cottages, and to some extent in green-houses, weighs on the average 15 ozs. per square foot. A better quality of window-glass, also used in the majority of green-houses, weighs 21 ozs. per square foot. Plate glass is of three qualities: (1) rough, used for skylights, $\frac{1}{4}$ inch thick and weighing 41 ozs. per square foot; (2) polished plate, $\frac{3}{8}$ inch thick, used for windows and large roofs; (3) polished best plate, $\frac{1}{2}$ inch thick, used for large windows.

The average cottage requires about 135 square feet of 15 oz. and 6 square feet of $\frac{1}{4}$ inch plate, a total weight of 126 lbs. 9 ozs. of sheet and 15 lbs. 6 ozs. of plate glass. A better house, such as is inhabited by middle-class people, will have windows of plate glass,

but this is quite a recent custom; and we may take as the average requirement of a house with three bedrooms and a bathroom, 250 square feet of glass of average weight, 26 ozs. per square foot, i.e., a total weight of 406·25 lbs.

The Census returns for 1911 show that England and Wales contained 7,141,781 houses, including flats. Supposing we assume that all these houses are no larger than cottages, they will contain, on the above figures, 452,360 tons of glass. A proportion of houses, however, would be of a better class and take much more glass.

Until recent years a great deal of glass was wasted in the form of slag. This, often brilliantly coloured, is still to be found in " rockeries," but is no longer lost, for as much as possible is now knocked off the pots and re-melted, while the pots themselves are broken up and used, in part for " grog " in new pots, and the remainder for concrete.

It is estimated that 45,000 tons of broken glass is annually lost in dustbin refuse, and the final resting-place of the glass will depend on the disposal of the rubbish (p. 178).

Slags.—Slag may be briefly defined as the dross produced in the smelting of metallic ores and other mineral substances. On account of the magnitude of the iron-industry, iron-furnace slags are by much the most important; the world's annual output of this kind of slag being about 50 million tons.

Slags fall into two classes: (1) silicate, and (2) non-silicate.

Silicate slags include blast-furnace slags, those from lead and copper smelting, and " tap cinder," i.e., the slag that collects below puddled iron. Non-silicate slags form two sub-classes: (*a*) basic, including " best tap " (magnetic oxide from the mill-furnace), litharge (lead oxide from the cupellation furnace), and " basic slag " (oxides of calcium, magnesium, and

iron, with calcium phosphate); (*b*) includes fluorides, borates, chlorides, sulphates, etc.

By far the most abundant slags are those derived from iron blast-furnaces. In 1855 the output of iron-slag in Great Britain was estimated at from 6 to 10 million tons; in 1879 the quantity produced in England alone was 8 million tons, a quantity which, loosely tipped, is almost equal in bulk to two Great Pyramides. In 1913 the output of pig-iron for the United Kingdom was 10,260,315 tons, which, on the ratio of $1\frac{1}{3}$ tons of slag for each ton of pig-iron produced, gives 13,680,420 tons of slag for the one year. The total output of pig-iron from 1740 to 1913 inclusive is estimated to have been 465,565,000 tons (see p. 51), which on the above ratio means the production of 620,753,000 tons of slag. If loosely tipped this quantity would occupy about 488,555,000 cubic yards, that is to say it would cover a square mile to the depth of 472 feet.

Ancient iron-slags are worth re-smelting. They have the approximate composition $2FeO,SiO_2$. At Liege, in 1859, about 28 to 30% of such slag was mixed with iron-ore and smelted. Those of the Forest of Dean were re-smelted for iron, and some of this slag was also made into black bottles at Bristol. So late as 1915 a thin deposit of slag, overgrown with turf, was being dug up near Four Ashes, South Staffordshire, and sent to the furnace to be re-smelted. How much of these ancient slags is now in existence in this country it is impossible to say; but the quantity cannot be great, for it was originally small as compared with the modern output, and the greater part has probably been re-smelted by this time and included in the statistics given above. We may therefore dismiss them as unimportant.

For a long time the only use of slag was for road-metal. Granulated slag had been used in mortar as early as 1770, but not in any quantity. Numerous

attempts were made between 1820 and 1840 to utilise it commercially by casting it into paving-blocks, but with indifferent success. Edward Parry Wales commenced the manufacture of slag-wool (similar to glass-wool) in 1840, but it did not become a recognised commercial product until 1875, when Krupp at Essen and Lürmann of Hanover began to make it. The latter firm also started to make slag-bricks about the same date. In 1873 the Tees Slag Co. of Middlesbrough commenced to make bricks containing only about 2·15% of lime and the same amount of calcined and ground iron-ore, the rest being slag; they also constructed large buildings of slag-concrete. In 1883 Puzzuolani, containing 85% of granulated slag and 15% of slaked lime was originated in Germany. Slag is also used in Germany to cheapen Portland cement. In 1880 the Cleveland Slag Works were using 14,000 tons of slag annually in the manufacture of bricks. These were made of 250 parts by weight of slag-sand with 3 of a calcined iron oxide, 3 of raw gypsum, and 24 of quicklime. Other products now made are artificial stone, kerb- and channelling-stone, and roofing- and bottle-glass. Only special kinds of slag can be used for glass-making.

The most important use of slag is still for road-metal. A new development is the introduction of tarred macadam, for which slag, being porous, is particularly useful. Some of the old tip-heaps are now being quarried for this purpose. Basic slag is by far the most easy to utilise. The slags from the acid-process weather into an earthy condition, and hitherto scarcely any use has been found for them. Basic slag, on the other hand, besides the uses above mentioned, is also valuable as a phosphatic manure.

The proportion of iron produced by the basic process is increasing. Though Thomas and Gilchrist introduced the process as recently as 1880, the basic slag produced in 1889 amounted to 600,000 tons. In

1896 the production of basic iron was 16% and in 1913 it was 36·6% of the British iron-output. The process is winning its way because it enables the abundant inferior ores to be utilised, while the slag is itself of value instead of a dead loss, as in the case of acid slag. Official statistics of the quantity of road-metal obtained from old slag-heaps, in cases where the worked face was over 20 feet high, were published in 1896 and 1897, and for the two years the output was 697,175 tons. In the latter year it was decided in the Law Courts that such workings were not legally quarries, and so statistics were dropped.

Cleveland slag has found important uses in the improvement of the Tees. The North and the South Gare Breakwaters, which project into the sea on the two sides of the estuary, are made of the slag. The North Gare is rather more than a mile long and the South Gare nearly $2\frac{1}{2}$ miles long. In 1878, when the South Gare had attained a length of 12,300 feet, it had already absorbed 3,253,356 tons of slag. The additional 500 feet, since completed, would bring the total quantity of slag used up to $3\frac{1}{2}$ million tons. The North Gare at the same rate will have required about $1\frac{1}{2}$ million tons, or 5 millions for the two breakwaters. In addition, training walls extending for 20 miles along the Tees had used, by 1878, about $1\frac{1}{3}$ million tons. A great deal of land, about 2,433 acres, between high and low tides has been filled up with slag and built on. In spite of the quantity that has been used, an immense mass of slag remains to be disposed of and is tipped along the river between Stockton and Redcar. In some cases it is built up into terraces which at the highest point, opposite Grangetown Station, must be nearly 200 feet high (see Plate). The total amount made in the Stockton-Middlesbrough district may be roughly estimated, for nearly all the Cleveland iron is smelted there, and up to 1905 about 250 million tons of Cleveland ore had been smelted. This would produce

TIP-HEAP OF MOLTEN SLAG, ABOUT 200 FEET HIGH, NEAR MIDDLESBROUGH, YORKSHIRE, AND RESEMBLING A LAVA-MASS WITH CLIFF-FACE.
(By permission of Messrs. Bolckow, Vaughan and Co.)

about 108 million tons of slag. In addition, large quantities of other ores have been dealt with in the district.

The following analyses of slags will give some idea of their chemical compositions.

Nos. 1 and 2 are Iron Blast Furnace slags showing the extreme members of a large number of analyses, while 3 is one of the intermediate members containing phosphorus. Nos. 4 and 5 are slags formed in the manufacture of steel by the Open Hearth process. Nos. 6 and 7 are slags formed in the manufacture of steel by the Basic Bessemer process. All seven are by Baron Juptner von Jonstoff.

	1	2	3	4	5	6	7
SiO_2	26.50	54.74	38.64	14.10	22.89	4.42	23.25
Al_2O_3	8.10	10.02	17.69	3.02	3.92	3.06	3.00
BaO	—	1.77	—	—	—	—	—
CaO	42.40	14.35	33.55	17.05	17.51	41.73	46.01
MgO	8.30	5.09	2.80	13.30	11.76	3.02	4.73
FeO	trace	4.51	4.56	28.73	19.68	19.46	6.77
MnO	10.76	7.43	1.05	22.84	22.98	4.29	5.50
CaS	4.87	0.02	0.70	—	—	—	0.78
P_2O_5	—	—	0.50	0.939	0.612	18.25	7.74
S	2.16	0.01	0.31	0.192	0.235	0.11	1.35
Fe_2O_3	—	—	—	—	—	5.66	1.62

The following analyses are given as illustrations of the composition of slags of metals other than iron. No. 1 is the average of seven analyses of lead slags from Freiberg, Germany, made in the first third of the nineteenth century. No. 2, a lead slag from Freiberg made in the last third of the nineteenth century. No. 3, a copper slag from Mansfeld, Germany. No. 4, a nickel slag from Sudbury, Canada.

	1	2	3	4
SiO_2	34.60	27.15	29.94	38.56
Al_2O_3	5.47	2.55	7.31	7.61
FeO	46.10	38.58	45.14	35.64
MnO	1.12	2.36	—	—
CaO	3.52	3.15	5.77	13.55
BaO	0.40	0.32	—	—
MgO	0.78	1.06	1.25	4.79
PbO	4.82	3.86	—	(trace of
ZnO	2.03	17.83	5.45	Ni mechanically
CuO	0.99	0.60	2.42	held)
SO_3	1.16	—	—	—
S	0.32	2.27	—	—
	101.31	99.73	97.28	100.15

It is customary to speak of blast furnace slags as " acid " or " basic " according as the acid radicles are greater or less than the basic radicles in amount. It is to be noted, however, that the most acid of the slags would be regarded as a basic rock, speaking geologically, while all the rest resemble the ultrabasic rocks in composition.

" Tap cinder " is the slag formed in the puddling furnaces. As it is used up in the manufacture of basic pig-iron and does not accumulate as a waste product we need not consider it further.

(2) *Non-silicate Slags.*—The slags containing borates, fluorides, chlorides, etc., are relatively small in amount. In nature they compare favourably in bulk with the abnormal rocks, some of which are so rare that they are to be seen only in the largest museums. Fluorspar, the use of which as a flux gives rise to the slags containing fluorides, had a total output for the 41 years, 1873-1913, of only 476,755 tons and some of this would be used up in the production of ornaments

and of hydrofluoric acid. As illustrations of borate and and chloride slags we may mention the glazes on enamelled wares. The salt (sodium chloride) used in the manufacture of glazed stoneware is approximately 1% of the weight of the ware.

In nature fluorides and borates are found in sedimentary rocks and saline deposits, but these have probably derived their fluorine and boron indirectly from volcanic gases. In deep-seated igneous rocks that have been subjected to the action of gases under pressure we find topaz, containing fluorine, and tourmaline, containing boron.

Waste Materials of Industries.—Colliery Waste and the Black Country: One of the largest accumulations of industrial waste is that covering the so-called Black Country, i.e., the district between Birmingham and Wolverhampton. The area of nearly continuous "made ground" is bounded approximately by a line following the Midland Railway from Wolverhampton to Wednesfield, thence along the Bentley Canal to its junction with the Anson Canal on the outskirts of Walsall. The boundary then continues to Wednesbury and West Bromwich, including these towns, and passes between West Smethwick and Smethwick. The line then passes by Oldbury, Burnt Tree, Tipton, Coseley, Lancesfield, Blakenhall, Monmore Green, and finally skirts the east side of Wolverhampton. The boundary of course is not a sharp one and it includes small areas, e.g., between Short Heath and Walsall, relatively free from waste. These are counterbalanced, however, by patches lying outside the area defined above. The waste is heaped up into a hummocky mass of very variable height, but if it were levelled down it would probably cover the whole area of $22\frac{1}{3}$ square miles to a uniform depth of 10 feet. In the section covered by the eastern half of the six-inch Ordnance Map Staffordshire 62 S.E., i.e., in a rectangle of exactly 3 square miles containing Bilston

and part of Willenhall, there are 92 coal-shafts and 6 bore-holes, $3\frac{1}{3}$ miles of railway, $1\frac{1}{8}$ miles of canal, and 135 ponds. These figures give some idea of the remarkable appearance of the district. In places the waste-heaps have been levelled for building sites, but elsewhere the surface is extremely uneven, with ponds lying in the hollows; and the mass may be compared to the kettle-drift left by a glacier. The materials are, firstly, shale brought up the coal-shafts; secondly, slag from blast-furnaces; and, thirdly, an endless variety of *débris*, such as chemical waste, broken bricks, the waste of all the varied industries carried on in South Staffordshire, together with the ashes and other rubbish thrown out of houses. On the above estimate, of an average of 10 feet spread over the whole $22\frac{1}{3}$ square miles, the bulk of the mass is $230\frac{1}{2}$ million cubic yards.

The other coal-fields offer similar deposits to those of the Black Country, although nowhere continuous over such a large area. We have already estimated that the total quantity of coal dug in the United Kingdom between 1500 and 1913 is 12,667 million cubic yards (see page 24). If we assume that a bulk of rock equal to half that of the coal has been brought out of the coal-pits, the rest being stowed below, then the contents of the various colliery-tips in the United Kingdom (we may almost say in Great Britain, the output of Ireland being very small) is about 6,333 million cubic yards of compact rock. In the fragmentary form in which it is found in tips it will occupy about 2 1/5 times the bulk of the original rock, or 13,933,700,000 cubic yards. This mass would cover an area of 10 square miles to the uniform depth of 1,350 feet.

Oil-shale Waste.—The oil-shale industry of Scotland is now confined to a triangular area west of Edinburgh, extending about 8 miles along the base of the triangle and 16 miles from base to apex. At one

ARTIFICIAL HILLS COMPOSED OF BURNT SHALE, PUMPHERSTON OIL WORKS, NEAR EDINBURGH.
(Geological survey photograph.)

time it was extensively mined at Burntisland, Fife, and also in a narrow belt on the west side of the Midlothian coal-field, where it was worked at Straiton and Burdiehouse.

The oil-shale is mined in a similar manner to coal, and, after being broken up into pieces as large as a man's fist, is passed into retorts, where it is subjected to a temperature of 1800°F. The waste product amounts to about 70 or 75% by weight of the original rock, and is tipped into " bings," which are usually 200 feet and occasionally even 300 feet in height. The dumps of one of the seven firms, in 1918, covered some 22 acres to a depth of about 200 feet. Considerable quantities have been used by building contractors for filling voids, and some has been used for footpaths and tennis-courts and for asphalt pavements. Attempts have been made to make artificial paving-slabs and building material, also to use it as a deodoriser, but they have met with little success. The temperature to which the shale has been subjected is so great that it is no longer amenable to brick-making processes: the shale has, in fact, been metamorphosed. By far the greater part of the waste is therefore dumped into the " bings," which form striking objects in the scenery. Mr H. M. Cadell compares the bings, which form small ranges of flat-topped hills with steep sides covered by screes, to the extinct volcanic cones of Mexico and other regions. " The spent shale when emptied out, warm from the retorts, is dark grey or black at first, but it becomes oxidised in time and assumes a bright brick-red tint."

The total output of oil-shale from 1873 to 1913, inclusive, was 78,054,140 tons, which at 1 1/5 cubic yards per ton would produce 93,664,968 cubic yards of waste, but probably the bulk is really a great deal more than this. The industry commenced in 1850, although there are no statistics until 1873, so that an inclusive estimate of 100 million cubic yards of baked

fragmental waste for the period up to the end of 1913 is not excessive. There is also the waste obtained from shafts and levels as in coal-mining and we may add perhaps 9 million cubic yards for this accessory waste.

Alkali Waste.—The old Leblanc or black ash process of making carbonate of soda and other chemicals produced a great mass of waste, which was dumped near the works. When fresh this tank-waste has the following composition:

Calcium sulphide	about	36	per cent
Calcium hydrate	,,	10	,, ,,
Calcium carbonate	,,	24	,, ,,
Iron sulphide	,,	7	,, ,,
Sodium sulphide	,,	2.14	,, ,,
		79.14	,, ,,

Coal and ashes are also present, causing the waste to be dark grey or black; but on exposure it weathers to a light yellow, in consequence of the oxidation of the iron sulphide to free sulphur and oxide of iron. The waste was spread out in layers from two to three feet thick and beaten down with spades to keep out air as much as possible, for if the oxidation became too rapid the mass might take fire. For many years the heap gives off a yellow liquid, which pollutes the streams and canals. It is decomposed even by the carbon dioxide of the atmosphere, but still more readily by the air of drains, or by the acid waste liquors from the works, and gives off sulphuretted hydrogen. The nuisance has now been abated, for sulphur is extracted from the fresh waste by Chance's process and the residue has then the following composition:

$CaCO_3$	84.79
$CaSO_4$	0.36
$CaSiO_3$	1.91
$MgCO_3$	1.34
Na_2CO_3	0.45
Na_2SO_4	0.07
Na_2SiO_3	1.47
Al_2O_3	1.19
FeS	1.05
S (free)	0.45
Coke	4.06
Sand	0.97
Moisture at 100°	0.58
Chemically combined H_2O and loss	1.31
	100.00
Combined SiO_2	1.71

This residue is of a totally different kind to that formerly deposited.

The Leblanc process is giving way before the ammonia-soda and electrolytic processes, which produce waste of another kind to be presently referred to. So extensively, however, has the Leblanc process been carried on in the past that the old waste heaps are characteristic of the scenery around Widnes, St Helens, and other centres of the industry. Mr E. Rhodes estimated that, in 1909, there were 500 acres of land at Widnes alone, heaped with the waste to the average height of 12 feet, and containing some 10 million tons of material. This, when fresh, would contain $1\frac{1}{2}$ million tons of sulphur. Mr Rhodes also estimated that the upper 8 feet of the mass had taken more than 30 years to accumulate. Mr S. B. Worthington, in evidence before the Rivers Pollution Commission about 1870, estimated that within the borough of St Helens the deposits of soda-waste covered nearly 50 acres of ground and contained upwards of a million cubic yards. Roughly one ton of sodium carbonate produced meant $1\frac{1}{2}$ to 2 tons of waste. At the Tyneside works the

waste is tipped into vessels and taken 3 miles out to sea; but this is only possible where the works are near a quay. In another case a piece of land was excavated to a considerable depth, filled with waste to within a yard of the surface and then earthed over. The land produced good crops, and there was no trouble with the drainage.

The first alkali-works in England was put up by Muspratt in 1824, and for over fifty years England controlled the world's market. The maximum output of sodium carbonate by the Leblanc process was reached in 1879-1883, when it amounted to about 500,000 tons per annum. Since then it has steadily declined. On the other hand the demand for sodium carbonate for glass-making has given place to one for sodium sulphate, made by the same process. The quantity of sulphuretted hydrogen that formerly escaped into the atmosphere may be imagined from the fact that 31,350 tons of sulphur were recovered from waste in 1892 alone. A great part of this sulphur would formerly have escaped as sulphuretted hydrogen into the air and there have been oxidised into sulphuric acid, which would have attacked crops, mortar in houses, and a host of other things.

The waste from the ammonia-soda process is of a totally different kind. The process was commenced by Solvay about 1866, and was introduced into England in 1874, when the first works was erected at Northwich, Cheshire. G. Martin and others estimate the present output of Cheshire alone at over 500,000 tons of sodium carbonate annually, and there is also a works at Fleetwood using the process. In 1888 England made 125,000 tons of sodium carbonate by this process and 428,614 tons in 1895 (in which year the output by the Leblanc process was 408,173 tons).

According to Lunge the waste product is a turbid liquid with the following composition, in grams per litre:

$CaCl_2$	75 to 85	grams
NaCl	48 to 39	,,
CaO (as $Ca(OH)_2$)	3 to 18	,,
$CaCO_3$	5 to 20	,,
$CaSO_4$	1 to 3	,,
$Mg(OH)_2$	2 to 12	,,
Fe_2O_3 and Al_2O_3	1 to 3	,,
SiO_2 and matters insoluble in HCl	2 to 6	,,

In nearly every case the liquor, after passing through settling-tanks, is run into the streams. The solid residue that settles is a mixture of slaked lime and calcium carbonate. Attempts have been made to use the calcium chloride, and at Northwich it is treated, at least in part, with carbon dioxide and crude zinc oxide, made by roasting zinc blende, or else with native zinc carbonate (calamine). Zinc chloride and calcium carbonate are produced, and the former is electrolysed, producing very pure zinc and chlorine, the latter being made into bleaching-powder. The calcium carbonate goes with the solid residue from the settling-tanks to the tip-heap, where it forms high white dumps. In 1901 the Northwich works produced 9 tons of bleaching-powder daily by this process. The material forming the dumps is mainly calcium carbonate and in some localities is used in the manufacture of Portland cement.

Metals.—Metals and alloys rarely occur as minerals, and never form rock-masses, and the metals we see so abundant everywhere are made by Man. In a previous chapter we have given figures to show the quantities made (p. 32 *et seq.*). Many metals have but a temporary existence. Iron, for instance, readily rusts and disappears when exposed to weather, unless special precautions are taken to preserve it. Copper, similarly, will turn into verdigris; lead is more resistant because the weathered surface protects the metal underneath. Silver rapidly tarnishes, especially if there are traces of sulphurous gases in the atmosphere,

as near towns. Tin is amongst the most stable of the metals. Gold and the platinum metals alone permanently resist weathering agents, but are all rare substances. It follows that although metallurgists have made enormous masses of metals since they began their work, their products are not permanent. As much iron was produced in the twenty-five years ending 1911 as in all the previous centuries, so that the volume of iron is growing rapidly. But only relics survive of that made in ancient times, the remainder has become rust and been disseminated through the soil, whence it will sooner or later find its way into the rivers and be mingled with ordinary sediments. Iron can be preserved by painting, or by embedding it in concrete: if neglected it perishes.

From the petrological point of view metals are the most ultrabasic of rocks. It is probable that, although almost unknown in the earth's crust, they nevertheless form the central core of the earth.

Concrete.—Concrete is an artificial breccia or conglomerate, according as it is made of angular fragments or round pebbles embedded in lime or cement. The "aggregate," as the fragments are called, is of varied character; pieces of brick, stone-quarry debris, and shingle from either the seashore or gravel-pits being the commonest constituents. In concrete it is necessary that the lime or cement should be sufficient to fill up the interstices of the sand and the combined lime and sand must completely fill the voids between the stones of the aggregate. In good concrete we should have one part of cement and three of sand mixed with twelve parts of gravel or eight parts of broken stone.

Although concrete seems to have been used abroad in very ancient times it was not until 1832 that it began to receive attention in England. Then came cases of failure due to bad engineering, which brought concrete into discredit for a time; but it is now being

used on an increasingly great scale, especially in the form of concrete reinforced with iron rods, which add considerably to its strength.

Sea-water and alkaline soils exert a chemical action on concrete and cause its disintegration. It is said, however, that if the cementing material is rendered impervious the concrete will resist sea-water. Concrete has the curious property of preserving iron embedded in it from rusting.

The amount of concrete in existence must be very great, but there are no figures by which it can be estimated. The Gatun locks on the Panama Canal alone contain over 2 million cubic yards, and all the Panama locks together contain $4\frac{1}{2}$ million cubic yards. A considerable proportion of the Portland cement output is used up in making concrete, of which it forms from one-sixteenth to one-twelfth, and the world's output of Portland cement in 1903 was from 7 to 8 million tons, while in 1908 the United States alone made 8,651,843 tons of cement.

Cements.—Cements are of two kinds: natural, and artificially mixed. The former are made from septaria or argillaceous limestones, in which the clay and limestone are present in the right proportions to form cement; the second class are made by mixing the necessary constituents. In making artificial cements there is a loss of 25% of rock.

Natural cements were first made in England and France about 1791, and for a time the industry developed rapidly. Parker, the first manufacturer, used septaria, i.e., nodules of clayey calcium carbonate occurring in certain clays, notably London clay. These are still used, a supply being obtained from the coast where the nodules have been washed out of the clays. The bulk of the natural cement, however, is obtained from the Lias, a part of which consists of layers of argillaceous limestone separated by beds of shale or clay. Each layer of stone is separated,

cleaned from shale and stored by itself. The layers vary slightly in composition, but do not differ much from the theoretical analysis of cement. It is easy by mixing them with shale and with one another to obtain the right composition. The rocks are ground to powder, burnt in a kiln to semi-fusion, and the clinker obtained is ground to an extremely fine powder and is then ready for use.

Hydraulic limes are made from purer limestones, and consequently when burnt they contain a quantity of quicklime in addition to the constituents of natural cement.

Portland Cement was first made in England by Joseph Aspdin in 1824. It is the most important of the artificial cements, and is obtained by burning to semi-fusion a mixture of approximately three parts of calcium carbonate, and one each of silica, alumina, and ferric oxide. The raw materials used are limestones and clays. By analysis of the raw materials it is possible to use a large variety of rocks by carefully blending them so that the composition of the mixture is nearly constant. Thus, cement-rock, clay, shale, slate, or slag; and limestone, chalk, marl or alkali waste, can be used. These constituents are finely powdered, mixed and then burnt at a temperature of about 1400° to 1500° C. The clinker is ground to finest powder as in the case of natural cement.

Now that it is possible to use the alkali waste both from the ammonia-soda and the Leblanc processes, after recovering the sulphur, in the latter case by Chance's method, there is a prospect of the eventual utilisation of the old alkali tip-heaps.

The chemical constitution of cements has caused much discussion. Messrs S. B. and W. B. Newberry, who have recently done important work on the subject, find that the essential ingredients of Portland Cement are tricalcic silicate ($3CaO,SiO_2$) with varying pro-

portions of dicalcic aluminate ($2CaO,Al_2O_3$). The other constituents are not essential.

Bricks.—From our point of view bricks can be grouped into two classes: sun-dried and burnt. The former are merely clay hardened in the sun, and in a humid climate may be expected to revert to the mud from which they were made, although their use has recently been advocated in England. Burnt bricks, however, have undergone a chemical change, similar to that undergone by clays that have been metamorphosed by an igneous mass, and bricks are artificial metamorphic rocks.

In countries where building-stone is rare or absent, brick-making is of great antiquity. Professor Banks, of Chicago, says that bricks were made in Mesopotamia ten thousand years ago, but these were merely dried in the sun. The earliest burnt bricks were made about 4500 B.C. In dry climates sun-dried bricks last a long time, and they are still being made in Spain, India, and other countries; but burnt bricks are far more permanent—in fact, when of good quality they seem to outlast almost all stone-work, unless they are accidentally broken. It is not uncommon to find both sun-dried and burnt bricks used in the same structure, as in the Great Wall of China. The Romans, who were expert makers of bricks and tiles, introduced them into this country before the fifth century, and their productions are still to be seen in many a building. After them the Anglo-Saxons and the Normans, until the time of Henry II., continued to make similar "wall-tiles," which have been confused with the Roman product. About 1320 the Flemish style of brick was introduced, together with their characteristic high gables and chimneys. Walls of this period have cores of rag-stones and mere facings of bricks; others were chequered in patterns carried out in black flints. This irregular style of building lasted until bricks came into general use,

about 1490, when brick-work began to be bonded in the Flemish manner. Until the reign of James I. walling was very bad, consisting of thin shells of brick-work with rubbish or turf between, while timber and designs in flint added variety to the brick-work. The earliest notices of brick-work in England relate to Cambridge in 1449, to London in 1453, and to Oxford in 1460. In Nottingham the first brick-built house was erected in 1615, and was pulled down about 1910. Previously, in Nottingham, bricks had been used for chimneys and filling in between the timbers. Doubtless lath and plaster buildings continued to be made for the poorer people for a long time after the introduction of bricks, in fact such buildings are not uncommon even now in country districts.

Many bricks of the Tudor period were probably imported from Holland. After the Great Fire of London bricks were used generally for rebuilding the city. The tax on bricks, lasting from 1784 to 1850, frequently caused brick-work to be replaced by stucco for outer walls. In the last thirty years of the nineteenth century the invention of the machine-made brick caused a great development in building, which lasted until the Transvaal war, when the demand for bricks fell off greatly.

The chief varieties of bricks are the following: vitrified, "sandrubbers," stock, common red, brindles, and fire-bricks. Other products called bricks, such as sand-lime, silica, magnesite, chrome, etc., differ essentially, inasmuch as they are not made from some form of clay. The differences between the varieties of bricks depend on (1) the composition of the clay or shale, (2) the process of mixing the clay and moulding the brick, (3) the temperature at which it is fired.

Petrographical Notes.—Vitrified bricks have been burnt until fusion has commenced. The superficial part is glassy, and under the microscope is seen to

contain microlites (incipient crystals), while the inner parts exhibit abundant crystallites such as are found in basalt that has been melted and allowed to cool slowly. The whole brick has not been melted, but it has been near melting point, and no doubt parts have been actually melted.

Brindles (so-called from their mottled colour) are hard bricks, giving a ringing metallic sound when struck. They have usually a rough exterior and are bluish-brown to deep red inside. They much resemble vitrified bricks, but microscopic sections are nearly opaque. The mineral constituents have been drastically altered.

Stock-bricks.—In the case of those from Sittingbourne partial fusion has taken place, especially in the vicinity of small fragments of " breeze." Quartz is little affected, though the chalk and iron appear as fluxing-agents here and there. Some parts of the " breeze " (cinder or coke) is left, and small particles of red and of white material are abundant. Some of these are merely burnt clay-pellets, others are remains of calcined chalk with minute cracks radiating from them.

As stock-bricks play a prominent part in the building of London an account of them is given in the chapter on London (see p. 183).

" *Sandrubbers,*" under the microscope, show the mineral grains quite clearly; quartz, often flint, occasional grains of hornblende, mica, felspar, etc., are all distinct as in the unburnt brick. But much of the slide is opaque, partly owing to the ferruginous matter that holds the grains together. The pyrites (FeS_2) present in the unburnt constituents has been destroyed.

Common Red Bricks.—In the more sandy kinds, which grade into " sandrubbers," the sand-grains are held very firmly together, usually with films of opaque clay between. The clay has yielded up a great deal

of its iron, and this frequently shows as stains. The clayey kinds are opaque in microsections.

Blue Bricks.—The colour of these bricks is due to melted oxide of iron and rarely penetrates far below the surface. They are prized for bridges, etc., where strength and resistance to damp are essential. Although the famous Staffordshire blue bricks come from quite a small area, the output in 1899 was at the rate of 40 millions annually.

Fire-bricks.—These bricks are made from the underclays of coal-seams. In thin sections they are translucent under the microscope.

Output of Bricks and Tiles.—We have no data by which to estimate the output of bricks and tiles, in Britain, before the eighteenth century. Such of the Roman tiles as escaped damage were incorporated in new buildings, although it is probable that many so-called Roman tiles are of Saxon or Norman manufacture (p. 215). One of the earliest outputs on record was in 1355, when 10 kilns at Wye in Kent made 98,500 plain tiles, 500 festeux (ridged), and 1,000 corners. In 1370 the product of 13 kilns was 168,000 plain, 650 festeux, and 900 corners, but the output was much reduced in the following year. These earlier bricks have in the course of time been broken up and incorporated with "made ground," except in a few buildings of antiquarian interest from their rarity. The first modern estimates of output that we have, date from the period when bricks were taxed. The numbers paying tax were:

In 1821 . . .	899,178,510
1833 . . .	1,035,000,000
1840 . . .	1,677,811,134
1847 . . .	2,193,829,491
1849 . . .	1,462,767,154

The size meantime was increasing. Under the Stuarts the thickness was $2\frac{1}{4}$ inches; but by 1850, or

thereabouts, it had increased to about 3 inches, though there was no standard size. In 1833 tiles were exempted from the tax and the size of bricks was ordered to be $8\frac{1}{2}$ by 4 by $2\frac{1}{2}$ inches. Also the mesh of the sieves used for sifting sea-coal ashes, to be mixed with the brick-earth, was ordered not to exceed $\frac{1}{4}$ inch. The fall in the output for 1849 was caused by the foreshadowed removal of the tax in the following year. Unfortunately, from that time forward, statistics of output were no longer kept. Humphrey Chamberlain estimated the output for 1855 to be about 1,800 millions. The number of burnt clay goods, including bricks, tiles, pipes, etc., was estimated in 1858 at 2,503,004,600 articles.

The condition of the industry before the introduction of railways is indicated by the statement, made in 1845, that a special Ipswich brick was "sometimes brought to London." Evidently bricks were rarely taken far from their place of manufacture.

The largest centre of brick-making at the present time is at Fletton, near Peterborough. In 1887 the industry was in its infancy; in 1890 about 50 millions, in 1900 about 500 millions, and in 1903 about 800 million bricks were made. Apart from the suitability of the clay, this enormous output is due to the enterprise of the manufacturers and to the proximity of a main railway-line to London, which has enabled Peterborough to destroy many of the small brickworks in other parts of the country. The coming of railways, in fact, has had a double effect on the production of bricks; it has concentrated the output into a few large centres supplying most of the country, and it has increased the total production by offering facilities for distribution. While only locally made bricks of inferior quality were available, building-stone was used for many purposes for which suitable bricks are now easily obtained.

For the output of recent years we have the Census

of Production, which gives the number of bricks made in 1907 as 4,794,739,000. As a cubic yard of clay makes about 250 bricks of standard size, 9 by $4\frac{3}{8}$ by 3 inches, the 1907 output would mean the burning of 19,178,956 cubic yards of clay. Some of the bricks, however, were not of standard size, the exceptions being for the most part larger, so that we may take the round number of $19\frac{1}{4}$ million cubic yards of clay burnt for bricks in 1907.

A Committee appointed by the Ministry of Reconstruction put the annual output for the three years 1911-13 at 2,805,748,000 bricks, which would require $11\frac{1}{4}$ million cubic yards of clay annually. In 1917 the approximate output was 1,052,246,000 bricks. The reduced output was of course due to the war, but also in part to the fact that only bricks fit for house-building were counted.

In 1907 the output of roofing- and street-paving tiles was 308,585,000. It has been found that 6,000 cubic yards of clay will produce 4,600,000 tiles, in addition to 400,000 broken or unsaleable ones. The year's output therefore means the burning of 4 million cubic yards of clay.

Life of Bricks and Tiles.—Bricks may resist ordinary agents of denudation for an indefinite time. Man, however, has produced some extraordinary agents, notably the gases that mingle with the air in manufacturing towns, where the greater part of the brick-work is to be found. In ordinary air the proportion of carbon dioxide is 0·030%; but Dr Angus Smith found that Manchester air during fogs contained as much as 0·0679%. This gas plays an important part in the decay of bricks containing calcium carbonate. Dry air will not attack bricks, but the carbon dioxide dissolving in rain-water forms with the calcium carbonate the soluble bicarbonate, which is then washed away. Under the law of partial pressures, when the air contains 0·06% of carbon dioxide rain-

water will hold in solution twice as much of the gas as when the normal amount, 0·03%, is present. The most powerful agent added to the air is, however, sulphuric acid. This is formed by the burning of coal, which always contains some iron sulphide (" brasses "). The air of Lille was found by A. Ladureau to contain 0·00018% by volume of sulphur dioxide. This gas is quickly oxidised and, dissolving in rain or fog as sulphuric acid, attacks anything within its reach. The smooth outer skin of a brick is a great protection to it, and if the corners of a brick become broken, rain-water is able to attack the more porous and less fully burnt interior. Moreover, the wet broken surface is frozen in winter and the surface flaked off. Soot also helps in the destruction of the bricks to which it clings. In some towns the bricks may be seen falling into a granular powder, although in the same district other bricks, e.g., the blue bricks of the railway-bridges, remain solid. But although a brick may fall to brick-dust it does not return to clay, for the burning has altered the clay chemically, and brick-dust will not puddle. Whether brick will return to clay in the course of ages it is impossible to say, but fragments of Roman tiles are not uncommonly dug up in the same condition as when they were made, say, one thousand five hundred years ago, and the Assyrian records made on bricks are unaltered after the lapse of four thousand years. Man appears therefore to have made a permanent record of himself, not in buildings, which are temporary, but in brick-dust—a new substance of his own creation. Whether this is really permanent in the true sense of the word is doubtful, for it is not unlikely that in a geological period the brick may undergo hydration and return to clay.

The great majority of brick buildings are less than a century old, and most of them are not half that age. It is true that there are brick buildings of Elizabethan

or Georgian date, but it is their comparative rarity that lends them their chief interest. The oldest house in England built entirely of brick is Little Wenham Hall, Suffolk, built in 1281. Since brick buildings have a comparatively brief existence, what becomes of the materials of which they are composed? In towns bricks may be directly attacked by the atmosphere as mentioned above, but the mortar is much more susceptible, and if a building is to stand it is necessary periodically to replace the mortar by the process called " pointing "; and sometimes to put in a number of new bricks. Old buildings soon fall into ruins if neglected, but frequently they are pulled down and the bricks carted away, either because the lease has expired, or it has become insanitary, or it is to be replaced by some other type of building, or it has been damaged by fire. As a rule about half of the bricks are fit to be used again after the mortar has been chipped off, but the other half will be too much damaged, and these will be broken up for concrete, or used for the foundations of roads as " hardcore." A good deal of broken brick is simply left lying about waste land, or dumped into old pits. Sooner or later the rubbish left on waste land has to be cleared up, and so the broken bricks will eventually be dealt with in one of the ways mentioned. In some cases it is crushed to powder to spread over garden paths. Tiles and drain-pipes suffer the same fate as bricks.

In a recent discussion it was stated that the average life of a Scotch tenement is one hundred and fifty years, and of an English cottage about sixty years, before they fall to pieces.

It is customary to use inferior bricks for the inside of the walls and better bricks for the outside; and when a building is demolished, the bricks used on the outside will on the average be sound enough for use on the inside of the new building erected on the site, while new bricks will be used for the outside.

The Quantity of Brick-work in England and Wales.—To form an estimate of the bulk of brick-work in the country we require to know (*a*) the number of each kind of brick building, (*b*) the average quantity of brick-work in each kind of building.

The Census returns for 1911 give us the numbers of buildings in England and Wales classified as (1) inhabited houses 7,141,781, and uninhabited 408,652, building 38,178; (2) places of worship 49,970; (3) government and municipal buildings 10,533; (4) shops 172,665; (5) offices 28,752; (6) warehouses, workshops, factories 139,977; (7) theatres and other places of amusement 3,050.

Not all these buildings are built of brick; the figures include stone buildings also, and, on the other hand, they do not include such buildings as stables, barns, and other out-buildings. All the brick-work used in railways and other engineering structures and in walls round gardens, yards, fields, parks, etc., is omitted. In many parts of England and Wales, particularly in rural districts and ancient towns, stone buildings still form a large part of the whole, and in some districts one sees a good many cottages, and even farmsteads, built of wood. The proportion, however, is very much less than it used to be, and is probably still diminishing. In pre-Victorian days local materials were generally used, for transport was difficult and expensive. On the introduction of railways, local materials began to be driven out by bricks and stone from a few great centres, such as Peterborough for bricks and Portland for stone. Except for public buildings, bricks became more and more universal. In a county like Northamptonshire, where limestones fit for building-stones are numerous, we may notice that until recent times buildings were nearly always constructed of stone, even to the roofs, which were covered with Collywestorn "slate"; but in Northampton, Peterborough, Kettering, and the

other towns, the buildings recently erected are nearly all of brick, and by now probably outnumber the older stone buildings considerably. On the whole, brick greatly predominates over stone in buildings, even public ones.

The additions and subtractions to be made to the census-figures, when separating the brick-work from the stone-work, are large, but perhaps roughly neutralise one another. No more than a rough approximation to the bulk of brick-work is possible at present, but even an approximation enables us to realise the important part taken by brick-work in modifying the surface of the earth. We shall therefore set off the stone buildings against the walls and engineering structures built of brick, and assume that all the buildings numbered by the Census are of brick.

Estimates of the number of bricks in a small dwelling-house vary from 20,000 to 30,000. The lower figure may be taken as the number in a workman's house, and 25,000 as the average for all kinds of dwelling-houses. On these figures the total of bricks in dwelling-houses in England and Wales at the date of the 1911 Census was 189,715,275,000; the houses being built at the time being included because they would be completed soon afterwards. The bricks would have a volume of approximately $355\frac{1}{3}$ million cubic yards, or 480,292,000 cubic yards of brick-work, produced by the burning of about 759 million cubic yards of clay.

It has not been found possible to estimate the brick-work in other types of buildings, but the following data from the "British Clayworker" give the quantities of bricks used in a few large and typical buildings. Winwick Asylum, Lancs., required about 20 million bricks; Whalley Asylum, Lancs., 20 to 25 millions; a new County Asylum for Hampshire, over 15 millions, of which 10 to 11 millions were common

bricks; Lewisham Park Hospital required 10 million bricks; Nottingham Workhouse 17 millions; the King's Sanatorium, Midhurst, about 10 millions. These figures indicate that in large institutions there are about 10,000 bricks per inhabitant. The number of people living in workhouses, prisons, asylums, hospitals, and other institutions in England and Wales on the night of the 1911 Census was 573,338; in barracks 135,755; a total of 709,085. We may therefore estimate the bricks in institutions in England and Wales at 7,090,850,000, equal to 17,951,000 cubic yards of brick-work. Adding this to the brick-work in houses, we have 498,243,000 cubic yards. The bulk of brick-work in places of worship, amusement, and business, 394,414 buildings in all, without counting the 10,533 government and municipal buildings in which the institutions mentioned above are doubtless included, can only be guessed at. It would, however, certainly be more than 2 million cubic yards, and so we estimate the total standing brick-work in England and Wales in 1911 as of the order of 500 million cubic yards.

This figure corresponds to a return of 7,588,611 houses, and assuming this proportion of total brick-work to brick-work in houses to hold for the other Census years, we get the figures in the third column in the table below. The second column gives the number of houses in England and Wales, whether inhabited, uninhabited, or building, at the dates given in the first column.

	Houses	Cubic yards
1801	1,632,431	107,557,613
1811	1,864,731	122,863,396
1821	2,177,137	143,447,202
1831	2,626,218	173,036,251
1841	3,144,636	207,193,776
1851	3,458,104	227,847,556
1861	3,951,504	260,356,695
1871	4,558,265	300,334,964

	Houses	Cubic yards
1881	5,264,609	346,874,557
1891	5,862,068	386,239,936
1901	6,771,693	446,173,308
1911	7,588,611	499,998,401

The third column gives the volume of the brick-work in the houses numbered in the second column.

On our assumption that the average life of brick-work is sixty years, the number of buildings destroyed in 1861 would be the same as the total number of buildings standing in 1801. Similarly in 1871 the number of buildings existing in 1811 would be destroyed. On our further assumption that half the brick-work is fit for use a second time, the amount destroyed in 1861 would be half the total bulk standing in 1801.

It may be objected with truth that public buildings last longer than sixty years. On the other hand shops and offices have, on the average, a shorter life than houses, for they are frequently pulled down before they have decayed, and improved buildings erected in their stead. On the whole, therefore, we may regard the sixty years of average life as applying to all brick-work in England and Wales.

A graph has been constructed on the assumption that the amount of brick-work destroyed in any year is half the quantity standing sixty years previously. Thus the bulk of brick-work standing in 1801 being 107,557,613 cubic yards (see above), the brick-work destroyed in 1861 will be 53,778,806 cubic yards. The graph has been produced backwards as a broken line for ten years. By Weddle's rule we find that the brick-work destroyed during the sixty years from 1861 to 1911 was 4,575 million cubic yards. All this brick-work has passed into " made ground," concrete, brick-dust, or has been disposed of in the other ways described on p. 222.

Although the brick-work used in the railways is included in the estimate of total brick-work given above, as a set-off against stone-work, it can be separately estimated.

The " British Clayworker " (1906-07) states that a new railway, 18 miles long, from Aynho to Ashenden, together with the necessary bridges, embankments, engine-sheds, and stations, required close on 18 million bricks in all, of various kinds. Of these, $13\frac{1}{2}$ millions were " brindles " from South Staffordshire. All the bricks had to be supplied during three years. From the same publication (Vols. XX and XXII, 1911-12 and 1913-14) it appears that the new Great Northern Railway from Cuffley to Stevenage requires about 35 million ordinary bricks. As illustrations of individual works we find (1910-11) that in rebuilding the Great Northern viaduct over the Trent at Radcliffe, near Nottingham, 2,710,450 common red, and 839,430 Staffordshire blue bricks were required. We are also told, by Smiles, that 23 million bricks and 8,000 tons of Roman cement were used in the lining of the summit tunnel at Littleborough, near Rochdale, which is 2,869 yards long.

To estimate the quantity of brick-work in the British railways we may take the Great Central Railway as typical of all (see p. 79). In the section, 106·175 miles long, from Quainton Road, Buckinghamshire, northwards, there are 638,374 cubic yards of brick-work, or an average of 6,012·47 cubic yards per mile of railway. Multiplying this number by 23,272, the mileage of railways in the British Isles, we find that they contain 139,922,202, say 140 million cubic yards of brick-work.

An immense mass of brick-work has been used in sewers. Thus it has been estimated that a new main sewer for Manchester, 31 miles long, would require 74 million bricks. The main sewers of London con-

tain about 700 million bricks, made from about 2,800,000 cubic yards of clay.

Drains, Tiles, and Pottery.—As a rule the manufacture of stoneware pipes is carried on in connection with a brick or terra-cotta works, for the pipes are usually made of clay scraps, shavings and cuttings, with the addition of bad or broken ware, saggers, tiles, old fire-bricks, or linings from kilns.

Earthenware pipes for sewers and house-drains were not generally used in England until about 1848, when a sudden demand arose. Previously they were made of rough stone, unevenly laid, and soon became choked. Rugby was one of the first towns to be completely drained by tubular earthenware drains. However, unglazed earthenware pipes found at Chester are believed to have been laid by the Romans, and the Babylonians used similar ware.

When made from raw material a suitable mixture contains from 30 to 40% of " fat " (sticky) clay mixed with a more open clay. A considerable part of the mixture consists of broken and burnt pottery, ground until it will pass through a sieve having, say, twelve or twenty-four meshes to the inch. The " grog," as this broken ware is called, may rise to as much as 50% when very " fat " clays are used, but may be very much less in other cases.

An analysis of a burnt pipe gave the following result: SiO_2, 70·50; Al_2O_3, 24·21; Fe_2O_3, 2·53; Lime, ·72; MgO, ·21; Alkalis (K_2O,Na_2O), ·84; total 100·01. Standard sizes of pipes are 4 inches inside bore, $\frac{5}{8}$ inch thick; 6-inch bore, $\frac{3}{4}$ inch thick; 9-inch bore, 1 inch thick; 12-inch bore, $1\frac{1}{8}$ inches thick; 15-inch bore, $1\frac{1}{4}$ inches thick; 18-inch bore, $1\frac{3}{8}$ inches thick. These thicknesses are for pipes that will be laid not more than 15 feet below the surface. In general, for all pipes over one foot in diameter the thickness should be one-twelfth the diameter. The length is variable, but generally is 2 feet 3 inches up to a 9-inch pipe,

including the socket of about 3 inches. Thicker pipes are usually 2 feet 9 inches long. Owing to the socket, 3 inches has to be deducted to find the effective length. The weight of a 4-inch burnt pipe is about 10 lbs. per foot; that is, the weight of $1\frac{1}{4}$ brick.

E. Reclus wrote that the drain-pipes laid down in England alone must amount to more than 6,200,000 miles. It is not easy to see how he obtained his figures, but it is certain that an enormous quantity of earthenware is buried in the ground in the form of drain-pipes. The quantity of material in drains connected with houses is estimated on p. 232, but agricultural drains offer a more difficult problem. The following estimate is more than usually doubtful, but it seems desirable to make it in order to give a rough idea of the mass of burnt clay in the soil.

According to Fream the distance apart of drains varies from 15 to 60 feet; 21 feet being an ordinary distance apart on heavy land. Here we shall take 33 feet as the mean distance apart, which gives $\frac{1}{4}$ mile of drains per acre. On Reclus's estimate of 6,200,000 miles of drain-pipes in England alone about 24,800,000 acres out of the 32,526,720 acres in the country would be drained, which seems excessive. Supposing the pipes to have a diameter of $2\frac{1}{2}$ inches and a thickness of $\frac{1}{2}$ an inch they would contain 3/5ths of a cubic yard of earthenware, or 384·1 cubic yards per square mile.

Estimates have recently been published of the quantity of materials required in the erection of 300,000 cottages, each containing a living-room, scullery, larder, coal store, w.c., and three bedrooms. The specifications are (*a*) for cottages with fireproof floors and concrete block partitions; or (*b*) with timber floors and partitions. The quantities for (*a*) and (*b*) differ only in a few items, and we shall confine our attention to (*a*). We shall only refer to the mineral

constituents, for organic substances, such as timber, do not concern us. The figures are useful as a basis for estimating the quantities of materials in existing houses. Quantities of metal are not given here as they are included in the totals given on pp. 32-51.

Materials	Quantities
Pan breeze or ashes	53,315 yds. cube
Hardcore	1,699,410 ,, ,,
Block slag or other hardcore for roads	3,159,990 ,, ,,
Clinker	2,093,970 ,, ,,
Limestone chippings for roads	790,335 ,, ,,
Flints for roads	1,404,435 ,, ,,
Gravel for roads	385,050 ,, ,,
Gravel for concrete	5,248,424 ,, ,,
Sand (including sand used in pointing walls)	5,423,352 ,, ,,
Portland cement (if the walls are pointed)	1,174,422 tons
12 in.×6 in. granitic concrete curb	30,000 ft. run
12 in.×6 in. granitic concrete curb, circular on plan to varying radii	1,338,000 ft. run
Bricks	5,431,330,148
Blue Staffordshire brick	25,290,000
Paving tiles	18,000,000
2 in. concrete partition blocks (18 in.×13½ in.)	594,720,000
4 in. glazed stoneware drain pipes	17,403,000
6 in. glazed stoneware drain pipes	2,025,000
9 in. glazed stoneware drain pipes	3,940,500
6 in. to 4 in. glazed stoneware taper pipes	106,500
9 in. to 6 in. glazed stoneware taper pipes	3,000
4 in. glazed stoneware bends	1,486,500
6 in. glazed stoneware bends	25,500
4 in. glazed stoneware junctions	595,500
6 in. glazed stoneware junctions	22,500
9 in. glazed stoneware junctions	75,000
4 in. glazed stoneware stoppers	121,500
18 in. lengths salt-glazed half-round stoneware channel pipes	295,500

Materials	Quantities
4 in. salt-glazed half-round channel pipes	487,500 ft. run
6 in. salt-glazed half-round channel pipes	108,000 ,, ,,
9 in. salt-glazed half-round channel pipes	87,000 ,, ,,
4 in. curved glazed half-round channel pipes	487,500 ,, ,,
6 in. curved glazed half-round channel pipes	85,500 ,, ,,
9 in. curved glazed half-round channel pipes	111,000 ,, ,,
4 in. three-quarter round salt-glazed branch channel bends	928,500
6 in. three-quarter round salt-glazed branch channel bends	24,000
9 in. three-quarter round salt-glazed branch channel bends	1,500
6 in. to 4 in. half-round salt-glazed main taper channel pipes, 2 ft. 3 in. long	1,500
6 in. to 4 in. half-round salt-glazed main taper channel pipes, 2 ft. 7½ in. long	7,500
6 in. to 4 in. half-round salt-glazed main taper channel pipes, 3 ft. 4½ in. long	3,000
6 in. to 4 in. half-round salt-glazed main taper channel pipes, 4 ft. 1½ in. long	7,500
6 in. to 4 in. curved salt-glazed main taper channel pipes, 1 ft. 10½ in. long	1,500
6 in. to 4 in. curved salt-glazed main taper channel pipes, 2 ft. 3 in. long	4,500
6 in. to 4 in. curved salt-glazed main taper channel pipes, 2 ft. 7½ in. long	6,000
6 in. to 4 in. curved salt-glazed main taper channel pipes, 3 ft. 4½ in. long	3,000

Materials	Quantities
6 in. to 4 in. curved salt-glazed main taper channel pipes, 4 ft. 1½ in. long	4,500
9 in.×6 in. curved salt-glazed main taper channel pipes, 4 ft. 1½ in. long	6,000
4 in. salt-glazed stoneware rain-water shoes	663,000
4 in. salt-glazed stoneware gullies	367,500
4 in. salt-glazed stoneware inspection eye gullies	64,500
4 in. salt-glazed stoneware intercepting traps with cleaning arm and stopper	18,000
6 in. salt-glazed stoneware intercepting traps with cleaning arm and stopper	22,500
12 in. diameter approved street gullies	46,500
Roofing tiles (for 150,000 houses)	620,062,500
Roofing slates (for 150,000 houses)	232,666,875 (18×10 in.)
	10,473,750 (11×7 in.)
Ridge tiles	7,500,000 ft. run
Asphalt	36,563 tons
Whiting	2,454 tons
15 oz. sheet glass	23,906,250 sq. ft.
White Morocco glass	7,650,000 sq. ft.

The quantity of brick-work has been estimated on p. 225 and the glass on p. 199, and we have now to consider the other materials.

The total of stone-ware required for 300,000 houses, as set forth in the table above, would weigh approximately 319,000 tons (weight after being burnt). The estimates do not mention pipes more than 9 inches in diameter, as the local authorities are responsible for the provision of main drainage, where not already laid down. Inquiries indicate that about 20% additional stone-ware is required for pipes over 9 inches wide, and so the 300,000 houses will need 383,000 tons of stone-ware for these additional pipes.

To find the weight of clay required to make this mass we must add 10% to allow for the loss in burning, and therefore the stone-ware represents the burning of 421,000 tons of clay, or, at 25 cwts. per cubic yard, of 336,800 cubic yards. In the manufacture about 478,750 tons of coal, producing at 5% about 24,000 tons of ashes, would be burnt, and about 3,850 tons of salt would be used for glazing the ware.

Inquiries show that the quantity of stone-ware mentioned in the estimates is above that actually used in some industrial districts for working-men's cottages. The figures given will, however, serve as the figures for the average house inhabited by various classes of people, and including the street drains. The 7,588,611 houses of the 1911 Census represent therefore the burning of about $8\frac{1}{2}$ million cubic yards of clay.

We have still to consider the tiles used in houses. The usual dimensions of paving-tiles are 6 inches × 6 inches × 1 inch, and therefore the 18 millions mentioned in the estimate will measure 6,933 cubic yards. A typical roofing tile measured $10\frac{1}{2}$ inches × $6\frac{1}{2}$ inches × $\frac{1}{2}$ inch; and 620,062,500 such tiles will contain 453,457 cubic yards. The quantity of roofing-tiles given in the table is for half the houses, the other half being assumed to be slated; but in houses already erected probably not more than 5% have tiled roofs, the remaining 95% being covered by slates. The roofs of 5% of the houses of the Census would contain, on this average, about 1,147,000 cubic yards of burnt clay, while the whole of the houses would contain paving-tiles made from 175,000 cubic yards of clay. In addition, a comparatively small quantity of burnt clay is represented by the ridge-tiles.

We may now add up the quantities of clay burnt to make up the houses of the Census of England and Wales for 1911, and we find that the total is approximately $768\frac{3}{4}$ million cubic yards. This amount

is the clay contained in the bricks, tiles, etc., in existing buildings; that used in bygone times and now destroyed represents an additional bulk of burnt clay.

This quantity represents the bricks, tiles, etc., in actual use. That used in bygone times and now destroyed represents an additional bulk of clay that has been burnt.

It is convenient to refer in this place to the quantities of slates required in houses, although slate is a natural and not an artificial material. On the assumption that roofing-slates have an average thickness of $\frac{1}{4}$ inch, 150,000 houses require 228,730 cubic yards of slate. Assuming that 95% of the houses of England and Wales are roofed with slates, these would have, in 1911, a volume of approximately $38\frac{1}{4}$ million cubic yards.

Ancient Cities.—In the chapter on London an account is given of " made ground ": that accumulation of rubbish which is Man's most permanent memorial. The cities of the ancient world are now represented for the most part by mounds, though masonry also is found in a good many cases. Some of the buildings, such as the Great Pyramid, have become famous as colossal engineering works. The mounds representing the sites of towns are sometimes mere accumulations of rubbish, but in many cases they have been deliberately heaped up as foundations for the buildings. The following notes on the bulk of some of these ancient monuments have been collected for me by Mr F. Middleton.

In the British Museum Guide Book, Budge gives the following measurements of the Great Pyramid of Khufu (Cheops), Egypt: height 451 feet; length of side 755 feet at base; area of top 30 feet square; area of base $12\frac{1}{2}$ acres. The Second Pyramid of Khafra (Chephren) measures: height 450 feet; length of side at base 700 feet. The Great Pyramid contains

3,148,000 cubic yards; and the Second Pyramid contains 2,222,000 cubic yards of masonry.

According to the Palestine Exploration Fund Handbook the mound at Gezer is ½ mile long and 1/10 mile in width; while that at Lachish has a height of 60 feet.

At Hassarlik (the ancient citadel of Troy), in Asia Minor, the ruins form a pile 52½ feet in height, consisting of 7 or 8 strata, each representing a city. (Quoted in the Harmsworth History of the World from Furtwangler).

Turning to Assyria and Babylonia, the mound on which the Palace of Sargon, Khorsabad (the ancient Dur Sharrukin), had, according to Perrot and Chipiez, a surface of 10 hectares. The mound was about 50 feet high and contained about 1,480,000 cubic yards.

Ragozin, in " Chaldea," says: " The platforms on which the palaces were built were 30 to 50 and even 60 feet high, executed with crude (unburnt) brick, mixed with earth and rubbish of all kinds, in more or less regular layers, faced with burnt brick (in Babylonia) but in Assyria with stone, at Mukayyar—the mound was faced with a wall 10 feet thick of red Kiln-dried brick cemented with bitumen."

G. Rawlinson, in " Five Great Monarchies of the Ancient Eastern World," writes that the walls of Nineveh have been completely traced and indicate a city three miles in length by less than 1½ miles in breadth, containing an area of about 1,800 English acres. Of this area less than one-tenth is occupied by ruins of any pretensions. There are two artificial mounds named Koyunjik (probably the site of the citadel), and Nebbi Yunus, the site of the palace.

Koyunjik is described as nearly flat with sides sloping at a steep angle. The greatest height of the mound is about 95 feet. The area is estimated at 100 acres and the entire mass is said to contain 14½ million tons of earth.

Nebbi Yunus covers an area of about 40 acres. The surface is mostly flat. The mound is calculated to contain 6½ million tons of earth. The houses of the common people were situated on the level ground between the two artificial mounds.

On the site of Babylon striking masses of ruins cover a space considerably larger than that which at Nineveh constitutes the whole area of the town. "The mounds . . . extend for a distance of above three miles. . . . The ruins consist chiefly of three great masses of building. The most northern—Babil—is a vast pile of brick-work of an irregular quadrilateral shape with precipitous sides furrowed by ravines and with a flat top. The southern face . . . extends a distance of about 200 yards. The East face . . . runs for about 180 yards, the western and northern faces are apparently much worn away. The greatest height of the Babil mound is 130 or 140 feet."

El Kasr mound is an oblong square about 700 yards long by 600 broad—its height above the plain is 70 feet.

The Amran mound is triangular, roughly 1,000 yards by 800 by 700 (height not given).

Another mound deserving distinct mention is El Homeira: 300 yards long by 100 wide; it attains an elevation of 60 to 70 feet.

At Larsa, now Sinkara, the ruins consist of a low circular platform about four and a half miles in circumference, rising gradually from the level of the plain to a central mound, the highest point of which attains an elevation of 70 feet.

In Great Britain also there are relics of ancient man in the form of mounds. Barrows and tumuli are familiar objects in many parts of the country, but mounds of a more unusual type are found in Essex where they are called "Red Hills." They are deposits of red burnt earth or clay, 3 to 6 feet thick, and form patches or low mounds, often a few acres in

extent. They stand on the alluvial marsh clay, and on the banks of the estuaries of the Colne, Crouch, and Blackwater Rivers alone they have been estimated at upwards of 240 in number. According to Chas. Dawson, in "The Antiquary," the mounds consist principally of red burnt earth, occasionally mixed with wood, ashes, or slag, and containing fragments of pottery. They are supposed to have been accumulated during the Late Celtic period, before the Roman occupation. It is suggested that they are ballast heaps discharged from ships sailing from distant pottery centres and taking clay on their voyages.

CHAPTER VII

ALTERATIONS OF THE SEA-COAST

Oscillatory movements have taken place along the coast-line of the British Isles, and there is geological evidence that the latest movement, as regards England and Wales, was a submergence of 60 feet. That this was in progress so late as Neolithic times, is shown by the discovery of stone-implements and bone needles of that age on submerged and buried land-surfaces at various places, as at Barry Dock near Cardiff, and at Southampton, and exposed during excavations. Clement Reid, in evidence before the Royal Commission on Coast Erosion and Afforestation, said: "When the sea stood at a level 60 feet lower than now, most of our coast was fringed by a belt of low ground, extending out approximately to what is now the ten-fathom line. On the landward side of this belt was, and in many places still is, a steep grassy slope, representing the position of a still more ancient line of cliff, the face of which has been hidden by rubbish washed from the slope above. The south and east coast of England, at the period with which we are dealing, must have been utterly unlike what we now see. Instead of bold cliffs, there was this wide coastal plain, like the plain which still extends for many miles west of Brighton, reaching a width of 8 miles at Selsey Bill. About 4,000 years ago a fairly rapid, but intermittent subsidence of the land, or rise of the sea set in; we do not yet know which it was, but for practical purposes the effect is the same. This rise of the sea-level flooded a great part of the

coastal plain and brought the waves within striking distance of the rising land behind. It also submerged the lower part of all our valleys, turning them into winding sea-locks, or fjords, which penetrated far into the land." Mr Reid thought " the rise of the sea-level may have been completed about 3,500 years ago." " Whatever may be its exact date, the completion of this rise is the starting point for our present inquiry. Only then commenced the coast erosion which we now see; only then did our existing shingle beaches and sand dunes begin to form."

There is no reason to suppose that submergence or emergence are now proceeding, except possibly in Northumberland and Durham, where Professor Lebour said, in evidence before the same Commission, that there appeared to have been a slight subsidence within the last fifty years. The evidence consists mainly in the loss of about one foot in some places, though for the most part less, in the period between the new and the old Ordnance maps. Some of the subsidence is ascribed to mining-operations and the falling-in of caverns in magnesian limestone districts, but it appeared to have occurred also in areas where there is no mining or cavern.

Reid said (Evidence before Coast Erosion Commission) that we know nothing as to the prospect of another change of level. " It is a problem of great importance, for a new rise or fall of the sea-level to the extent of a few feet would have most disastrous effects on all our coasts and harbours, and would seriously interfere with our inland drainage until things were again adjusted."

Outlying sand-banks or shoals may affect the coast in various ways. In some cases they afford a protection from breakers; in other cases, where they lie parallel to the coast, the velocity of tidal currents in the channels so formed is often increased, and may lead to greater submarine scour. The point of attack of

the sea may be altered by the shifting in position of sand-banks, and this is possibly the explanation of the intermittent character of the erosion on many places on the east coast. During the twenty years between the dates of the Admiralty charts published in 1885 and 1906 numerous and important changes have occurred in the position of banks or shoals off Yarmouth and Lowestoft. They involved an enormous displacement of material at depths down to the five-fathom line, though but little change was observed at the ten-fathom line. Erosion beneath low-water level is intensified by boring animals, of which the sponge *Cliona* is the commonest. The bivalves *Pholas* and *Saxicava*, and the worm *Leucodore*, are also important denuding agents. Reid estimated the denudation due to the weakening of the chalk by numerous borings to be as much as an inch per annum, in infested areas.

The best natural protection from erosion by the sea is the shingle and sand accumulated round the coast-line. Beach material is practically all derived from the land, mainly by the erosion of cliffs, although in exceptional storms a little may come up from beneath low-water level. Materials travel along the shore in definite directions, but may be arrested by headlands and rivers, or by artificial works such as groynes, harbours and piers. The direction is usually that of the prevailing winds, due to the waves, which are governed by winds. Some authorities think that flood tides help, but others think that their apparent assistance is a mere coincidence. From the Tweed to the Thames the normal trend is from north to south; from the south coast to the Thames it is from west to east.

Since almost all beach material is derived from erosion of land, the supply is not inexhaustible; and beach material should not be interfered with where it protects the coast. As shingle becomes worn away, it is replaced by erosion at some other part of the coast,

and it follows that, if coast protection became nearly universal, shingle would wear out and disappear, thus bringing about the necessity for further protection. In certain cases shingle may be removed with advantage, e.g., near harbours or estuaries, which might be blocked. Danger from erosion may also follow quarrying or dredging on the foreshore and beneath low-water mark, where the rock or loose material acts as a protection to the coast.

The following case described by Mr Hansford Worth[1] affords an illustration of the danger of removing shingle. South of Street Head, on the Devon coast, there is a beach five miles long, not replenished from local sources. In 1896 permission was given to dredge shingle and other materials from the foreshore opposite Hallsands, and from 1897-1901 an estimated quantity of 650,000 tons was removed, after which the licence was cancelled. Up to this time there had been no erosion, but from 1901 to 1904 many houses, sea-walls, and a road were washed away, the beach having fallen on an average 12 feet and in places as much as 19 feet.

Again, on the coast south of the River Wear, erosion is aggravated by the removal of beach material, and is said to have caused the lowering of the beach by about 10 or 12 feet in twenty-five years. The increased erosion along 34 miles of the coast of Holderness has been ascribed to the holding up of two million tons of shingle by works at Bridlington. Erosion amounts to 45 acres per annum along the 34 miles. Walton, in Essex, has suffered greatly from erosion, caused partly by the dredging of cement-stones off the shore, and partly by the removal, still continued (in 1911), of large quantities of materials from the foreshore. Between 1874 and 1906 at least

[1] When not in the Lists of Works at the end of this volume the information in this chapter is from the Report of the Royal Commission on Coast Erosion and Afforestation.

56 acres of land were washed away. In the sixty years before 1906 Clacton lost at least 50 acres, in part caused by removal of material. The erosion, east of Rhyl, is probably due to dredging in the Clwyd. Over two million tons of gravel have been shipped to Liverpool for harbour works, but this has been stopped and gravel is now accumulating on the foreshore. At Watchet, Somerset, the removal of limestone boulders from the coast for use in Welsh blast-furnaces is said, by Sir A. Acland Hood, to be causing grave injury. Much of the erosion at Pilling, Lancashire, is said to date from the eighteenth century, when large boulders were taken from Rossall Point to Liverpool for paving the streets. In Scotland erosion has been assisted in the Loch Ryan district, by the shipping of stones from the foreshore to Belfast to be used as road-metal. At Goldspie, in Sutherland, and near Nairn, removal of stones has had the same result. At East Sands, near St Andrews, about 3,000 loads of shingle were carted away between 1904-7 and this is no doubt a main cause of the erosion which has amounted to the loss of a strip of land 20 to 30 feet wide during the last ten years. About a hundred years ago the Bar of Banff was of considerable dimensions, and afforded valuable pasture. Owing to the removal of shingle it has become much attenuated during the last thirty years. In 1902 and 1903 several thousand tons of shingle were taken for concrete during the extension of the pier at Macduff Harbour, and this so weakened the bar that it was driven bodily inland. The original site is now submerged and some 30 to 40 acres of land have disappeared. The County of Antrim has 2,300 miles of roads requiring to be kept in order, most of them small accommodation roads to farms. As there are no gravel-pits within the country, and no sand inland, sand and shingle are removed from the shores for roads and buildings. Also, sand is carted some distance inland for use as a dressing for clay-land.

Other cases could be given, but the above will suffice to illustrate this cause of erosion.

It does not seem possible to estimate the amount of erosian caused, in the past, by the removal of shingle. Before the time of Telford much shingle was used on the coast-roads, for which purpose it was carried to inland towns also for centuries (see p. 105). The most serious case of erosion in this country, that of the Holderness coast, which has lost 115 square miles since 55 B.C., is considered to be partly due to this cause. In addition to shingle, much beach-material has been taken away for marling agricultural land. Even after more suitable road-stone had replaced shingle, the pebbles still continued to be collected for concrete and other purposes; e.g., large quantities of flint-pebbles have been removed and ground to the finest powder for use in the manufacture of porcelain and stone-tiles. Others are used in flint-mills. On the coast of Normandy, where the flint-pebbles are particularly in demand on account of their purity, it is estimated that 121,000 metric tons were removed in 1907. To yield this quantity annually, it is necessary that two million cubic metres of chalk should be destroyed by the sea, and Mr Cloez estimates that this is about the annual amount of denudation of the chalk cliffs. It appears therefore that the removal of flints on the Normandy coast is responsible for the denudation of the chalk cliffs there, for if they were left alone they would protect the cliffs from erosion.

An allied cause of erosion is the quarrying of stone in the cliffs. This cause is said to have been in action at Kinaird, Aberdeenshire, and also east and west of Lyme Regis, Dorset.

The usual effect of protecting the coast in one place is to initiate or promote erosion in a neighbouring part, generally by stopping the flow of material along the shore. Erosion has occurred, in consequence of defence works, near Bridlington, Sheringham, Cromer,

Corton near Lowestoft, Hastings, Bexhill, Eastbourne, Brighton, Hove, Blackpool, and Silloth, while the places named, amongst many others, have all been protected and in many cases groynes and piers have resulted in a gain of land. A salient pier at a harbour entrance causes an accumulation of beach-materials to windward and leaves the shore to leeward subject to erosion, necessitating protection there. Sea-walls, unless properly constructed, are agents of their own destruction, for if they are not well designed, the waves that break against them tend, on recoiling, to scoop out beach-material at their feet. If not held in place by groynes, or other means, the walls are undermined.

Erosion is sometimes greatly retarded by the draining of the cliffs, and the consequent prevention of landslips. This has been carried out at Scarborough, Frinton in Essex, and Shorncliffe.

It would be wearisome to mention all the protective works along the British coast, and a full account is given in the Report of the Royal Commission on Coast Erosion, 1911. Some instances only will be given. At Felixstowe there is a sea-wall two miles long, also 120 groyns; Eastbourne has a sea-wall two miles long and 81 timber groynes. Near Minehead and Blue Anchor, in Somerset, 12 miles of coast have been protected, and on the eastern bank of the Bristol Channel a length of 44 miles of shore-line is protected. The London and North-Western Railway extends along the North Welsh coast for a long way, and its engineering works have proved a considerable protection to the land. In Cheshire, the sea-wall east of Hoylake, known as the Wallasey Embankment, is one of the greatest defences in the country. It is made of masonry and concrete, and is nearly 4,400 yards long. At Blackwall are 3 miles of sea-wall.

Another method of protection is to encourage the growth of marram grass, and some other plants, on

sand-dunes. The plants bind the loose sand together and prevent it from being blown inland; so offering a barrier to the sea and at the same time keeping the sand from overwhelming the land behind. The method has been adopted near Wells, and also between Winterton and Happisburgh, all in Norfolk; also at St Andrews, in Scotland. At Shoreham, Sussex, a hedge of tamarisk protects a shingle-beach from erosion. The mud-flat between Hurst Castle and Southampton is covered by three species of Rice-grass (*Spartina*), which helps to reclaim it. Although the grasses grew here naturally, one if not two species are not natives of Britain and must have been introduced by Man.

There is no clear line of separation between works for coast protection and works for reclamation from the sea. On the whole Man is adding to the area of the country, for the lands reclaimed are considerably larger than those lost through his activities. Though the Romans set up sea-banks, not much reclamation was carried out until a comparatively recent date, for in the Middle Ages, reclamation and protective works were scarcely thought of, while erosion was being aided by the removal of shingle, etc. In considering whether, on the whole, Man's activities have added to or diminished the area of the land, it would be necessary to balance these opposite activities, which at present can scarcely be done.

According to the third Report (1911) of the Commission already cited, it appears that, within a period of about thirty-five years, an area of 4,692 acres has been lost to the sea in England and Wales, and 35,444 acres gained; a nett gain of 30,752 acres. Scotland lost 815 acres and gained 4,704 acres, a nett gain of 3,889 acres. Ireland lost 1,132 and gained 7,853 acres, a nett gain of 6,721 acres.

Cases of reclamation of land due to the Romans are known. In the Wash they constructed the Roman Bank some seventeen hundred years ago, and this,

aided by later works, has led to the silting up of nearly 63,500 acres. A part of Romney Marsh is also due to them. On the west bank of the Severn there are large Roman reclamations called the Caldicott and Wentlloog Levels, and amounting to about 20,000 acres of valuable agricultural land.

After the Roman period there were practically no engineering works on the coast, with the exception of Liverpool Old Haven, made in 1332-1356, until the sixteenth century, when a few harbours and dockyards were made, all (according to present ideas) on a small scale; and after that time coastal defence works and reclamations became increasingly more numerous and important.

The land gained from the sea is situated almost entirely in tidal estuaries, and, to a very great extent, is due to deposition of silt, whereas the losses are chiefly on the open coast. Gains by deposition of silt are not always intentional, but may be caused accidentally by interference with natural conditions.

Cases where the foreshore has been filled up by direct action of Man are relatively few. This has taken place at Workington, where the slag from the iron-furnaces is not only filling up large areas of foreshore, but is in part drifted along the coast, and, mixed with natural shingle, is causing accretion on the south coast of Walney Island. In this case, although the result is clearly due to Man, it is unintentional. All the gravel used for concrete for the Manchester Ship Canal came from the south end of Walney Island, but no erosion has been caused, since the loss is made good by stones and the slag from Workington.

At the Stirling Hill Quarries, South of Peterhead, the source of Peterhead Granite, the rubbish is tipped over a cliff into deep water. Although this has been going on for many years and the stone includes blocks up to half a ton in weight, yet no stone is ever seen at the surface. It is believed, however, that some of it

may reappear as shingle farther along the coast. At Tintagel, Cornwall, rubbish from the slate quarries is thrown over the cliffs, as at Stirling Hill, and is swept away.

The most striking case of reclamation by direct filling up of the foreshore is probably to be found in the Tees estuary. Slag from the Middlesbrough iron-furnaces was taken in vessels and dumped on the boundaries of the area to be reclaimed. When the surface of the slag-tips had risen above high-water mark, railways were laid down along them and the slag was then shot into the enclosed area until it was filled up. Some 4,270 acres have been filled or are in process of being filled up. Slag being of indestructible character forms a good foundation for buildings. The Tees banks are protected by training walls above and below Middlesbrough for about 20 miles. At first they were made of clay and slag, but afterwards of slag only, and between 1859 and 1877 there had been deposited 1,356,628 tons of slag. The walls vary in depth from 12 to 40 feet, and rise from 4 to 7 feet above low-water. The high-tide groynes, put up between 1808 and 1852, had caused considerable accretions on the foreshore. Later a high-water embankment, 14 miles long, completed in 1887, was built of soil faced on the seaward side with slag. Up to 31st October, 1885, the dredgings from the channel amounted to 18,557,820 tons, which, in early years, beginning 1854, were deposited in the old channels, but after the banks formed had reached low-tide level the finer material was washed away, leaving the stones. The two great breakwaters of slag are referred to on page 202.

The River Humber, which contains more silt than any other English river, is caused to deposit its burden by the erection of obstacles, such as fences. This process has been carried on since the time of Charles II., and near Sunk Island alone a total of about 7,000 acres of tidal mud has been converted into

rich arable land. Probably not more than another 1,600 acres can be reclaimed without injury to navigation.

In the Wash about 2,200 acres have been reclaimed in the King's Lynn district since 1857. It has been found that not more than 250 acres can be dealt with at one time, and that it takes from twenty to thirty years for the warp (silt) to deposit over the area before it becomes land fit to enclose. By that time its surface should be nearly level with spring-tide mark, otherwise it is practically useless.

In Romney Marsh, according to Mr George Dowker, the sequence of events was as follows: Firstly, a shallow bay existed into which the rivers Rother, Tillingham, and Bude, on the way to their outlet near Romney, deposited their silt, so that the northern half of the Marsh had become dry land before the Roman period. Around this bay sand-hills formed. At times the rivers overflowed, and, depositing silt, raised their banks on either side. A slight depression of the land commenced and has continued. Beaches accumulated, and in consequence of their formation and the raising of the river bed by silt, the river forsook its channel, in the thirteenth century, and has since flowed into the sea at Rye.

An ancient vessel, wrecked about the twelfth century, in a branch of the Rother north of the Isle of Oxney, was found covered by 10 feet of silt. At the date of the wreck the present channel was blocked artificially, but the barriers had been entirely removed in 1635, and since then the river has flowed by the southern channel. Mr Dowker shows on his map various "innings," or areas reclaimed from the marsh at various dates. At present Denge Ness is growing seawards at the rate of six yards annually, by the accumulation of beach deposits. Immediately to the south, opposite Winchelsea, the sea has washed away a corresponding quantity of shingle on which the original Winchelsea probably stood.

The action of Man seems to have been limited to draining the marsh and converting it into pasture. Remains of forests are found, and sometimes they bear the marks of tools. The great Rhie Wall, which extends across the marsh from Appledore to New Romney, a distance of about nine miles, according to Mr Dowker was originally a natural river-bank, subsequently raised and altered by the Barons of the Cinque Port of Romney. Dymchurch Wall is maintained, at great expense, to protect the marsh south of Hythe from inundation by the sea. On the whole it seems that Romney Marsh is mainly a natural feature which, to a great extent, has defied Man's efforts to fix its bounds. We read of towns washed away and ports silted up, in spite of struggles to preserve the *status quo*. Probably twentieth century Man would have fought more successfully against the changes worked by the sea and the rivers.

On the Dee, the first reclamation, so far as is known, was made in 1637. In 1732, Nathaniel Kinderley began a navigable canal from Chester, and finished it in 1737. By 1857 some 4,500 acres had been reclaimed on the north side of the channel. In 1870-76, a bank was made across the estuary from Connah's Quay to Burton Point, a distance of 3,700 yards, but the following year the tide broke through and it has never been repaired. However, 1,200 acres remain in a partially reclaimed condition as a result of the making of the bank.

On the Mersey, about 1,230 acres of tidal lands have been reclaimed during the last century, and now form the site of Liverpool Docks. About 550 acres remain to be reclaimed and are intended to be used for more dock extension. It is thought undesirable to reclaim more land above Liverpool as the volume of water necessary to scour the channel would be dangerously reduced.

From the Ribble, more particularly near Preston,

about 7,400 acres were reclaimed in the last century. In Morecambe Bay the sea has broken into a tract of land that had been reclaimed. It is stated that 35 square miles of foreshore are suitable for reclamation. The embankments of the Furness Railway, between Grange and Arnside, and at Holker, between Cartmell and Ulverston, have reclaimed hundreds of acres, but the area is covered with sand and of little value.

In the Clyde large areas have been reclaimed in past times. The Clyde Navigation Trust has purchased some of the reclaimed land and removed it to ensure a greater tidal range in the river.

In the Firth of Forth the foreshore is, in places, being filled up with waste materials, which practically form a raised beach. The rubbish comes in part from colliery tip-heaps, but coal-ash from the salt-pans, which until about 1882 extended for miles along the coast, forms another source; a third is the slag-blocks that were discharged from the iron-works at Kinneil. This works is now dismantled, but during its forty years of activity it reclaimed about 30 acres of land. In addition, " warping " has been carried on near Bo'ness by Mr H. M. Cadell.

Holland offers the most striking instances of land reclamation. It is said that in Roman times travellers doubted whether Holland was land or water. So soft is the ground that on a site in Amsterdam, two men have bored to a depth of 50 feet in 20 minutes, using a hand-auger. In many parts of the country, and particularly in Groningen, there are isolated artificial mounds about 30 to 40 feet high, and it was on these mounds that early man had his habitation. The soil of which the mounds are composed is often used as a top dressing for the fields and, when levelled, the mounds frequently prove to be museums of antiquities dating back to the Stone Age. Only a third part of Holland, that towards the south-east, is more than a metre above

average high-water mark; the remainder of the country is practically below that level.

As early as the twelfth century the Dutch were renowned for their skill in coastal defence. In 1277 the country near the mouth of the Ems was inundated, and for more than two centuries the flooded land remained a swamp. The struggle with the sea is still proceeding; since the sixteenth century over 12,500 acres on the coast of Friesland, and about 57,000 acres on the coast of Groningen have been reclaimed. There was formerly an inland sea in the centre of Friesland, with an area of 25,000 acres, through which in Roman times there flowed the River Ijssel. Between the thirteenth and seventeenth centuries embankments were made, but proved too low, for in 1750 a storm destroyed the dams in places and the sea flooded the land as far as the city of Groningen, destroying 20,000 people. Since then much of this flooded land has been reclaimed.

Before the seventeenth century unusually high tides used to inundate the country around Alkmaar and Haarlem, but between 1540 and 1648 about 63,000 acres were reclaimed. The Haarlem Lake was originally a vast swamp intersected by small rivers, its area of 45,000 acres being continually added to by fresh floods. In 1840 the lake was drained, and an area 13 miles long by 6 broad and covered by 13 feet of water became arable land. The large island of Walcheren, Zeeland, was originally represented by dozens of small marshy islands. At the close of the fourteenth century these were united by a series of dams. Reclamations at the mouths of the Maas and Scheldt have increased the size of Holland by about 250,000 acres of agricultural land, since the twelfth century.

Holland, within its area of 12,648 square miles, contains about 1,600 miles of sea-dykes. Until the sixteenth century the sand-dunes were continually changing their positions and shapes, but planting with

grasses was then commenced, the principal ones being *Ammophila arenaria* (helm-grass) and *Triticum junceum*. The dunes are now almost stationary everywhere. This dune-barrier, on which the existence of Holland depends is in many places from one to three miles wide and in some places attains a height of 130 feet. To prevent the landward travel of the dunes, the Dutch cultivate (in addition to grasses) trees, mostly fir, beech, and oak, at the foot of the dunes, and shrubs on the slope. The sand is bound together by rootlets, and any blown over the crest of the dunes is caught by the trees. That the dunes moved, before these precautions were taken, is proved by the fact that a buried Roman village has been uncovered.

The Zuider Zee is the result of the sea breaking in and engulfing 780,000 people and a million acres. For a long time plans have been made for reclaiming parts of it.

In spite of the great works already completed, Marsh considered that in Holland the loss of land to the sea, since the commencement of the Christian era, considerably exceeded the area reclaimed.

Docks.—In 1900 the mercantile docks in the United Kingdom numbered 230, with a tidal water surface of 2,750 acres, besides 388 tidal and other basins. There were also 210 acres of timber pools and 279 graving docks. In 1903 Mr J. C. Hawkshaw stated that wet docks (i.e., docks with a lock or tidal basin closed by gates) were almost confined to this country and neighbouring coasts of Europe. The Mersey docks had quays equal to two-thirds the length of those of the rest of the world.

In many cases the materials excavated are superficial deposits, such as peat and alluvium. The Tilbury Docks, for example, were excavated mainly in these deposits and in gravel, although hard chalk was found below the gravel. The total excavation was $4\frac{1}{2}$ million cubic yards of material, all used up in making

the quays, which are in general 12 feet above the original surface level.

In 1896 the extension of Keyham dockyard, Devonport, required the excavation of 740,000 cubic yards of "made ground," 4,322,500 cubic yards of mud and 1,286,500 cubic yards of rock (slate). At the Avonmouth Dock, made between 1868 and 1877, the total excavation was $1\frac{3}{4}$ million cubic yards, chiefly clay. In 1881 to 1885, during the making of the Alexandra Dock, Hull, 3,350,000 cubic yards of materials were excavated and 661,000 cubic yards were dredged.

Liverpool was an important harbour even in 1550, and in 1565 there were 15 vessels of 268 tons burden trading there. The original port was a narrow creek, called the Pool, which extended inland from the site of the present Custom House for about a mile in a north-easterly direction along what is now Paradise Street. Vessels were loaded and discharged by boats in the river, or by grounding them on the banks of the creek and using carts at low water. In 1708, during Queen Anne's reign, the construction of a dock of 4 acres at the mouth of the old Pool was authorised. Both dock and creek have long since been filled in and built over, and the site is only indicated now by a depression. The value of Liverpool harbour is largely due to the curious shape of the Mersey estuary. This is a bottle-neck, being about 3 miles wide at Ellesmere Port and only 1,000 yards at Liverpool, while up-stream the estuary ends at Runcorn Gap. The upland water entering the estuary amounts to no more than 2 or 3 million cubic yards in 12 hours, whereas the tidal water passing New Brighton, at the end of the peninsula at the Cheshire side, is about 710 million cubic yards at high spring and 281 million at low tides. The tidal area of the estuary is 22,500 acres, mostly filled with sand of which 17,300 acres are exposed at low-water spring tides. The sand-banks are continually shifting,

and so prevented from becoming permanent land. This is very important to the harbour, because the tidal reservoir, filling and discharging past Liverpool, is thereby maintained. For more than six miles, and for a width of from 700 to 2,200 feet, the foreshore between high and low water, on the Lancashire side, has been enclosed by a sea-wall, except at the entrances to docks. The earlier docks were made abreast of the original one mentioned above, to the north and the south, and included the Salthouse, George's and Prince's group. George's Dock was made under the Act of 1761 and has now been filled up and built over. George's and Seacombe Ferry Basins were filled up to make the landing-stage. From 1708 onwards a long series of Acts authorised extensions of the docks. Mr G. F. Lyster, from whose paper these details are taken, made a sea-wall parallel with the low-water margin of the river, about 1870, from the north pier of Canada Basin to Rimrose Brook, a distance of about 6,400 feet. The coping is about 15 feet above high-water mark. A parade 20 feet wide behind a wall 4 feet high, tops the wall, and the parade is four feet above the roadway. The wall is built for the greater part on boulder clay. It is faced with granite from South Scotland, and has a backing of sandstone. A wall of red sandstone at Rimrose, across the foreshore, completes the enclosure, and there is a granite fort at the salient. The area enclosed is 300 acres of sand, resting on boulder clay. New extensions of the docks were begun in 1873. North of the Canada Dock the excavations were chiefly in boulder clay overlain by a thin coating of sand. The total excavation to a depth of 14 feet below datum (i.e., 18·67 feet below Ordnance Datum) was about 6 million cubic yards. Much brick clay was obtained, and over 30 million bricks were made from it and used in the buildings. To the south of Rimrose Brook new extensions were also made, the

first being the Herculaneum Dock, and here the slope of a hill, rising to 70 feet above the quay level, had to be excavated. Over a million cubic yards of New Red Sandstone were blasted and deposited 10 miles beyond the river-bar. At Tranmere, Birkenhead, the outer basin to the growing docks required the excavation of 80,000 cubic yards of sandstone and 520,000 cubic yards of clay and sand. In 1889 the total area of the Liverpool Docks was 363 acres 3,925 square yards, not counting the Basins; while at Birkenhead there were 159 acres 4,535 square yards of docks, as well as Birkenhead Basin, 4 acres 2,843 square yards. The total area of the docks on both sides of the river was 545 acres 3,064 square yards, and the quays were 35 miles 80 yards long. Graving and Garston Docks were additional.

According to Mr William Ashton it is highly probable that in Roman times the wide channel between Liverpool and Birkenhead was dry land, and that there was a fresh-water lake between Garston and Runcorn that drained into the Dee below Chester, along a valley now occupied by the Shropshire Union Canal. Besides other evidence, Mr Ashton lays stress on the total absence of any reference to the Mersey estuary in Roman works and its absence from Ptolemy's maps. If Mr Ashton is right, it follows that Man, in reclaiming the Mersey mud-flats, is only partially undoing the work done by the sea in post-Roman times.

These are but a few instances of the engineering works done on harbours all round the British coasts. Unfortunately, the information obtainable is insufficient to enable the quantitative results to be summarised.

Although so much material has been excavated in making docks, the nett result is the reclamation of land. For the most part docks replace mud-flats, covered by water at high-tide and neither true land nor sea. This debateable territory is resolved partly into land and

partly into permanent water (the actual dock), and the boundary of the coast is sharply defined by walls, at the outer margin of the former foreshore.

Reclamations of land are confined to shallow water. An important result of engineering operations along the coast is the sharpening of the foreshore. By comparison of the Ordnance Surveys of different dates, Col. Holland found a nett loss of foreshore of 31,232 acres in England and Wales; 8,371 acres in Scotland; and 7,471 acres in Ireland—a total loss for the British Isles of 47,074 acres. This loss is estimated by comparing the low-water marks of two surveys, taken at an interval of about thirty-five years. The reduction of foreshore is caused, on the one hand by the filling up of shallow water areas when reclaiming land, and on the other by dredging shallow waters in the vicinity of ports. The effect is to steepen the gradient of the foreshore, and one result of this is to minimise any change in the coast-line due to an alteration of sea-level.

An interesting biological result of the reduction of foreshore is the increased " struggle for existence " that must follow amongst the animals and plants that live between high- and low-water marks. Investigation would probably show a great reduction, or even the total extermination of some species, and modifications in the survivors.

Dredging.—Dredging has two aspects: if it is carried out in the sea it directly assists denudation by deepening shallow water, but if in a river and if the material dredged is dumped on the land dredging may appear to oppose denudation by replacing on land material in transit to the sea. It is, however, more usual to drop the dredged material into deep water, in which case it is definitely lost to the coastal shelf.

The effects of dredging are temporary, for new sediment is continually being swept in to replace that removed; nevertheless dredged material is placed in

positions other than those intended by Nature, and there is human interference to that extent. Also dredging encourages the deposition of material to replace that removed.

The quantities of soft rocks dredged are enormous, but it is only since 1890 that the invention of powerful machines has enabled the operation to be carried on at anything approaching the present rate.

In the six years 1897-1903 there were dredged from the Mississippi 6,129,000 cubic yards. A contract was made in 1904 to remove 42½ million cubic yards of sand and gravel from New York Harbour, in order to open the Ambrose Channel. The channel is 2,000 feet wide and 40 feet deep, and the work was performed by two dredgers. Prior to 1898 the Government had removed 32½ million cubic yards. In 1899 a contract was made and carried out for making a channel, 1,200 feet wide and 40 feet deep at mean low tide on the east side of the harbour; and 22 million cubic yards of sand and mud were removed.

The River Elbe annually deposits some 640,000 cubic yards of silt at the entrance to the Kaiser Wilhelm Canal, and this is dredged and carried two miles out to sea. In the ten years from 1888 to 1898 dredgers removed 50,358,000 cubic yards, chiefly of clayey sand from the Lower Weser.

The larger of two dredgers used in the Mersey removed 2,000,000 cubic yards in 1898. It was stated by Mr Haupt in 1911 that up to that time 130 million tons had been dredged from the Mersey bar and channel (equal to about 106 million cubic yards).

In the case of the Clyde all dredgings obtained up to 1862 were used to reclaim land; after that date most of the material was taken out to sea. Between 1844 and 1879 dredging amounted to about 23 million cubic yards. It was estimated that, of 992,354 cubic yards dredged in 1872, about 299,000 cubic yards were brought down by the river and sewers, and 693,000

cubic yards was new material produced by deepening and widening the harbour and river.

Up to 31st October, 1885, the total amount dredged from the River Tees was 18,557,820 tons, equal to about 15,130,000 cubic yards, while more than 124,000 cubic yards of rock was removed by blasting. The river has also been straightened between Stockton and the sea by cutting through the meanders. One of these cuttings, that of Portrock, is 1,100 yards long by 250 yards wide and 16 feet deep. For 7 miles above and 13 miles below Middlesbrough the river is kept in place by training-walls, which during the period 1859-1877 absorbed 1,356,628 tons of iron slag.

Canals, also, require dredging; thus, from the Trent and Mersey Canal over 1,100,000 cubic yards of earth were dredged in the course of twenty years.

Some of these cases of dredging are inland, and have nothing to do with coastal changes, but it is simpler to mention them here than in another chapter.

As an instance of a foreign navigation the case of the River Volga, in Russia, may be mentioned. The navigation of the Volga is maintained by dredging over 2,500 miles of the river and its tributaries. On Russian waterways there were made 56·9 miles of cuttings in 1899, involving the excavation of 5,160,300 cubic yards of materials; in 1901, 145·5 miles of cutting were made and 9,260,000 cubic yards excavated. The total for three years was 282·5 miles of cutting made and 20,421,200 cubic yards excavated.

CHAPTER VIII

THE CIRCULATION OF WATER

CIRCULATING water is one of the most potent of all Geological Agents. In this chapter we shall discuss Man's interference with the flow of water, whether in amount or in direction, and whether above or beneath the surface of the ground. A fundamental alteration in the circulation of water is affected when the rainfall is modified, but it seems desirable to discuss this alteration in the chapter on Climate, and here we deal only with water flowing on or under the land.

Land-Drainage.—The first Act of Parliament authorising the expenditure of public money for land-drainage was passed in 1840, though it remained inoperative and another Act was passed in 1846. Previous to that date such drainage as was done was undertaken by tenants, as a rule, and after the lapse of twelve or fourteen years it ceased to be of any value, because the drain-pipes were laid only one or two feet below the surface, and, even if they remained unbroken, they had become choked with roots. However, draining was sometimes carried out before drain-pipes were invented, for Arthur Young, in 1770, mentioned several cases where agricultural land had been improved by draining. He states that there were three sizes of drains, 4 to 5 feet deep, 3 feet, and $\frac{3}{4}$ yards respectively. They were filled with stones to within 7 or 8 inches of the top, and a cart-load of 40 bushels of stones would fill 7 yards.

Mr Bailey Denton estimated, in 1856, that Great

Britain contained 22,890,000 acres of wet lands requiring drainage, while the area of the land permanently drained was only 1,365,000 acres, including the area of London and suburbs, 450,000 acres. Drain-pipes were scarcely known in 1843, and the earliest were of three inches diameter, with a slit along the whole length. Pipes of about one inch diameter began to be used about this time. Land-drainage is by no means completed, but has received such an impetus since 1846, that Reclus estimated, in 1887, that there were not less than 6,200,000 miles of drain-pipes in England alone. The basis of his calculation is not stated, and it is permissible to doubt if the figure is more than a guess.

Owing to the expense of drainage, a method has been re-introduced in the last few years that does not require the use of pipes. On this plan a special plough is used, which makes a cavity somewhat like an inverted T. The cavity serves as a drain, and is said to last a number of years before it becomes choked and the land requires re-draining. Improved drainage and deeper ploughing, both introduced between 1840 and 1860, have caused the disappearance of many a perennial small stream, hedgerow ditch, or burn; and have also reduced the proportion of rainfall available for percolation, thereby diminishing springs and underground water supplies.

By improving land-drainage the speed with which the rainfall reaches the sea is increased, thereby rendering the climate drier than before, and even causing droughts. Streams, both large and small, are straightened, in part to gain land, since a straight course occupies less space than does a tortuous one, in part to prevent floods by increasing the velocity of the stream, and in other cases to render them more easily navigable.

Mr G. W. Lamplugh has pointed out that when the population of a country becomes settled, streams

have to be " tamed." They cannot be permitted to flow in variable and winding courses and to overflow their banks in wet weather; stabilised channels are therefore made, reduced in width and rendered deeper and more gutter-like than they were naturally. Streams, even small ones, frequently offer the best boundaries to proprietary rights, and cannot therefore be permitted to leave the courses once marked out for them. Fords become fewer; the stream is graded uniformly, to produce a more equable flow of water. In a later stage of civilisation even estuaries are tamed in a similar manner. Mr Lamplugh gives some of the results of the taming of streams as follows. Run-off becomes much more rapid than before. Under natural conditions streams overloaded with detritus choke their channels and spread over the bordering flats, on which they deposit most of their surplus burden. But when the stream has been stabilised the muddy flood-water is pent in its channel, and moves forward with little opportunity to clear itself. Hence under the new conditions there is a more rapid transport of the finer waste to the sea, or lake, and presumably a heavier deposit of material on mud-flats in the tidal estuaries, where the current is arrested. But sand, gravel, and boulders, pushed along the bottom of a stream, are removed by Man and usually put beyond the reach of further transport. Very generally these dredgings are used to raise the flood-banks, and so much detritus, naturally spread over a valley floor, becomes piled up close to the stabilised watercourse. When this process has been long continued there is often to be noted a slight, but well-defined, rise in the ground in the immediate neighbourhood of the river, on both sides; and in many cases the water-surface is considerably above the level of some of the alluvial floor of the valley. This condition is obviously unstable, and would soon be destroyed if Man's control were relaxed. On the

whole, therefore, the natural deepening of valleys is checked, and in many places stopped; but the degradation of the land as a whole may be accelerated (since more detritus reaches the sea than under natural conditions). The main tendency is towards a slow flattening of the land-contours, with a gradual reduction in the relative value of incised features, in this agreeing, according to Mr Lamplugh, with most other human operations affecting the surface of the earth.

The effect of drainage is well illustrated by the case of the Fenland. In Saxon and later times it was, according to Miller and Skertchley, "a vast open plain, covered for the most part with deep sedge, dotted with thickets of alder and willow, abounding in shallow lakes, temporary and permanent, and overflowed in its lowest parts, nearly, if not every winter. The fishing and fowling were valuable in the extreme, and the drier portions afforded a luxuriant pasture land."

The Romans probably commenced the drainage of the Fenland. They made the Car Dyke, a catch-water drain round the inland border, to prevent extraneous water from reaching the fens. The Dyke probably commenced at Cambridge and certainly extended from Ramsay to Lincoln. It was formerly used for navigation, but is now a mere ditch. The Romans also made interior drains, which have been almost obliterated, but the old West Lode and Hammond Beck are, in all probability, their work. Of the Early English Period there are very few records, but it is known that Deeping Fen was partly drained in the reign of Henry I. As time passed the population increased, but the drainage deteriorated, because the outfalls were allowed to become obstructed by silt, and drains and sea-walls fell into decay. The Fenland relapsed into its original condition of morass until Rennie, in 1801 to 1818, drained the East, West, and Wildmore Fens. He revived the Roman plan of

a catchwater drain round the fen border and the conduction of the water by successively larger drains into the main arterial channel. For a time the results were excellent; but presently silt accumulated at the sluices, and the peaty land was lowered by drying to the extent of two feet, so that in 1866 the East Fen was again under water. However, pumps were put in to lift the water to the dykes, and the Fenland was again drained. The area of the Fenland is 1,306 square miles, including about 109 square miles reclaimed from the sea since Roman times. It is said that though the early Victorian summer mornings were almost always foggy, the district is now no more foggy than any other part of the country.

Irrigation.—Irrigation is the opposite to Drainage; it is the artificial process of supplying water to crops in countries where the rainfall is either insufficient or comes at the wrong season for their cultivation. In the above sense irrigation scarcely exists in England. There are many cases where sewage is run on to the land, but the object in these cases is not to supplement a deficient water supply, but to dispose of sewage in the most harmless and profitable manner. If we consider the earth as a whole, however, irrigation is one of the most powerful agents used by Man.

In British India the area under sown crops in 1905 was 226,060,000 acres, and of these, 44,090,000 acres were irrigated, i.e., 19·5% of the whole. In the Indian Native States the area under sown crops was 71,070,000 acres and the proportion irrigated was 7,760,000, or 10·9% of the area sown. It was estimated that in British India, of the 44 million acres irrigated, 13 millions were supplied by wells, 17 millions from canals, 8 millions from tanks (i.e., reservoirs), and 6 millions in other ways. Col. Baird Smith reported, in 1860, that there were 70,000 wells lined with masonry, and 280,000 temporary wells (i.e., unlined), between the Jumna and the Ganges, irri-

gating 1,470,000 acres; but a part of these are now replaced by the Ganges Canal. Madras Province has 30,000 tanks, and in the Central Provinces there are 50,000 private tanks, used for irrigation. In the delta of the Godavari alone, there are 500 miles of main and branch canals, and about 1,700 miles of distribution channels. In India evaporation and plants use up 59% of the rainfall, 35% runs off, and 6% is available for irrigation.

Ceylon shows the remains of immense irrigation works of great antiquity. One tank, that at Tissewewa, had originally an area of probably 4,000 acres, and after 2,000 years have passed about 1,400 yards of embankment is still in fair preservation.

Next to India the United States has probably the most extensive irrigation works. Some of these also date back to prehistoric times. In 1542 remains of a large canal were found in the Gila Valley, Arizona, and could be followed round the city of Casa Grande for 9 miles. Near Mesa City, Salt River, one of the largest of these ancient canals had been excavated for several hundred feet, through hard volcanic rock, to a depth of from 20 to 30 feet. The rock showed signs of chipping, and great numbers of worn-out stone axes and hammers were found, an interesting instance of engineering by stone age man. The early Spanish settlers resorted to irrigation, but the first modern Americans to use it were the Mormons in 1847. All the more recent works in South California have been made since 1880.

The arid region of the United States is about two-fifths of the whole country, and the amount irrigable is from 60 to 100 million acres. The Reclamation Act of 1902 led to large projects, which were commenced in the following year. Up to June, 1917, the United States Reclamation Service had constructed 9,970 miles of canals, 296·9 miles lined with concrete, and 4·1 miles lined with wood; drains

and ditches 1,180 miles; 94 tunnels having an aggregate length of 141,987 feet (nearly 27 miles); storage and diversional dams containing 2,083,376 cubic yards of masonry, 9,818,103 cubic yards of earth, and 1,155,763 cubic yards of " rock fill and crib," total contents 13,057,242 cubic yards; reservoirs with an aggregate available capacity of 9,193,800 acre-feet (i.e., equal to an area of 9,193,800 acres covered with water one foot in depth); dikes and levées 94·5 miles long and containing 4,430,190 cubic yards of constructional material; bridges 5,817, of aggregate length 131,326 feet; culverts 6,988, of aggregate length 243,033 feet; pipes made of concrete 556,918 feet, of metal 239,400 feet, terra cotta (tiles) 1,146,770 feet; wood 331,380 feet, total 12,174,468 feet; flumes made of concrete 94 of aggregate length 14,870 feet, metal 674 of length 142,084 feet, wood 1,679 of length 362,134 feet; buildings 1,184; wells 391 of aggregate depth 34,583 feet; roads 902 miles; paving 749,395 square yards; railways 83 miles. The total excavation was 149,786,534 cubic yards, made up of earth, 133,043,727 cubic yards; indurated material 8,882,812 cubic yards, and rock 7,859,995 cubic yards. Of cement 2,741,763 barrels, of concrete 2,942,775 cubic yards, and " rip-rap " (stones thrown together without order) 1,527,920 cubic yards were used.

In Mesopotamia, Sir W. Wilcocks has propounded schemes for irrigating $3\frac{1}{2}$ million acres. The necessary engineering works will require 818,000 cubic yards of masonry and 182,200,000 cubic yards of earthwork. The part under construction in 1912 was about one-third of the whole and will irrigate 1,360,000 acres, using 280,000 cubic yards of masonry and 68 million cubic yards of earthwork. Now that Mesopotamia has been conquered it is probable that the full scheme will soon be an accomplished fact.

Irrigation was carried on in Egypt under the Pharaohs, though few traces of these early works now

exist. Since English supervision commenced in 1884, great works have been carried out, including the Assuan dam, begun in 1888 and enlarged soon after completion, making its storage capacity 3,267 million cubic yards. Also, in the four years 1883-86 alone, there were earthworks erected in the Nile delta containing 9,275,000 cubic yards.

Java is mentioned on page 314. Many other countries use irrigation, but it is unnecessary to refer to them in detail. In the future there will probably be large schemes in many parts of the world, for instance in the desert of Central Australia.

The largest artesian area in the world is in Australia, and comprises 569,000 square miles, of which 376,000 is in Queensland, 90,000 in South Australia, 83,000 in New South Wales, and 20,000 in Northern Territory. Water was first struck in 1879 at Killara, in New South Wales. The supply comes from a porous sandstone of Triassic age. The intake comprises an area of 60,000 square miles in Queensland and 10,000 square miles in New South Wales, mostly mountainous country, and therefore usually free from drought. The boreholes number 3,000, and maintain a daily flow of 480,485,000 gallons. The deepest is 5,045 feet; but as a typical one we may mention the Rowena boring, which struck water at 2,670 feet and gives about 925,000 gallons a day. The water is distributed by canals aggregating 41 miles in length, and supplies 21 sheep runs containing 55,405 acres. A sheep requires about $2\frac{1}{2}$ acres.

Waterways.—Waterways comprise rivers, canalised rivers (navigations), and canals. In England and Wales, according to the Canal Commission, there are 3,639 miles of canals and navigations, of which 1,927 miles are true canals. In addition, about 345 miles of canals have been converted into railways or are derelict. As the length of the rivers of England and Wales is about 7,929 miles, against 1,927 miles of

existing canals, it appears that Man has added 24⅓% of new waterways to the natural streams.

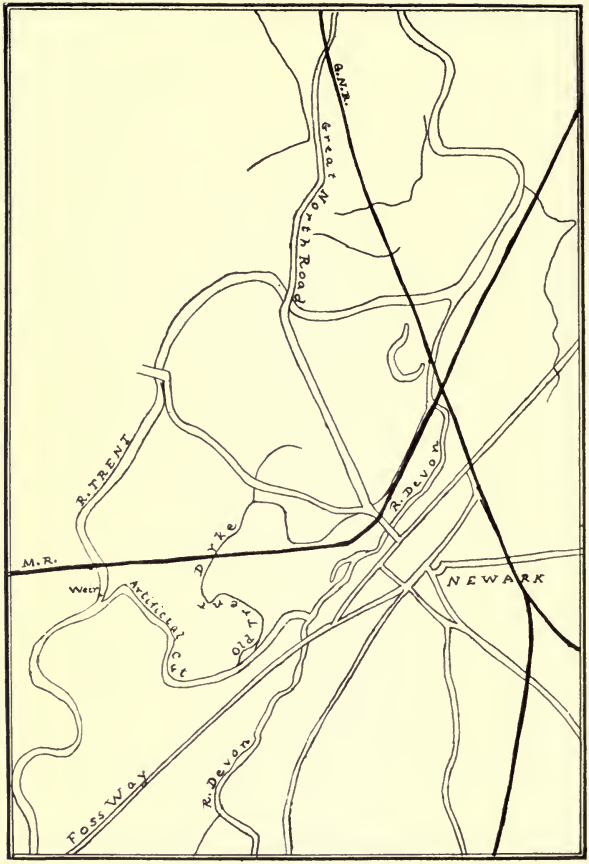
Navigable rivers left in their natural condition are comparatively few, and those few are found for the most part in countries that are only partially civilised. Even the great Nile, flowing in the relatively unaltered continent of Africa, has been greatly modified. The difference between a canalised river, or navigation as it is called, and a canal, is that the latter is " an entirely artificial cut, which in many cases crosses the watersheds and river-basins at various levels. It requires that streams and water-courses be led to it or that mechanical means be employed to raise water to its summit and other reaches. A canalised river, on the other hand, is dependent only on the river flow and not on any artificial means of supply." A canalised river, although its direction may be altered somewhat, follows in the main the course of some natural river, and is in fact that river more or less improved for navigation. Sometimes the alterations are so extensive that the river is almost as artificial as a canal. The rivers Clyde and Tyne are examples. If instead of constructing the Manchester Ship Canal the Irwell-Mersey had been improved until ocean-going ships could reach Manchester, the engineering changes would have been as great as those involved in making the canal, and we should have had a navigation comparable to that of the Clyde, which a century ago had only from 3 to 6 feet of water and now has 24 feet, as the result of dredging. In 1758 the river was 15 inches deep at low water at Glasgow, and until 1818 no sea-going vessels could reach the town. On the other hand, Canterbury and Winchester were once centres of sea-borne trade. The Stour at Canterbury was once a navigable estuary—the focus of six Kentish ports.

When Queen Victoria came to the throne the River

Tyne was in its natural condition. "It was a tortuous shallow stream, full of sand-banks and eccentric eddies which at Newcastle men might ford at low tide." Men were living in 1895 who had forded the river below Newcastle, and had seen women, with skirts kilted up, gathering coals from the bed of the river. They had seen also brigs aground at the Quay. In 1849 the depth on the bar was the same as in 1813; about 6 feet. The ships of the Tyne Steamer Shipping Co., no more than 400 to 500 tons burthen, and drawing 13 to 15 feet of water, had to complete loading at North Shields. Not until late in the fifties could they steam direct to Newcastle. On the river there were no docks and few quays.

In 1895 a 5,000-ton ship could cross the bar and sail up to Elswick or Dunston. On passing the bar one saw piers, one 3,059 feet, the other 5,317 feet long, and inside them a broad expanse of water wide and deep enough for a squadron to ride at anchor and still leave a navigable channel open. In Shields Harbour a number of sand-banks have disappeared, and for a distance of 8,000 feet vessels can moor in over 30 feet of water at low-water spring tides. Bill Point, which was a cliff 72 feet high, protruding into midstream, has been cut back 400 feet from the point. This involved the excavation of 2,000,000 tons of soil and rock, which were for the most part dumped in deep water. A new channel was made through Blaydon Haugh to cut off a loop.

In 1838 dredging began, and 21,379 tons were removed; in 1850 the amount was 66,452 tons. The Tyne Commission began work in 1851, and dredging became more vigorous, until in 1866 the maximum of 5,273,585 tons was removed. Including 5,000,000 tons from the Albert Edward Dock and some from the Northumberland Dock, 95,000,000 tons have been dredged from the river between 1838 and 1894 and deposited in the sea.



MAP OF NEWARK-ON-TRENT, SHOWING THE DIVERSION OF A RIVER BY MAN.

(Based upon the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.)

The map is given as an example of the way in which a river has been altered by Man.

The River Trent at one time flowed past Newark along what is now the Old Trent Dyke. Later, it altered its course and took the present channel, passing some two miles to the north-west of the town. The deserted channel became reduced to a mere ditch, still traceable. In the interests of navigation, however, the upper part of the deserted channel has been turned into a canal, and this continued across country into the River Devon, which flowed past Newark and entered the Trent below the town. A large proportion of Trent water now flows along the artificial channel, which has become known as the Trent. Strictly speaking, however, Newark-on-Trent ought to be called Newark-on-Devon.

This example of river alteration is by no means an extreme case; dozens of instances of equal or greater importance could be given.

A canal requires a supply of water to replace losses by (1) evaporation from the water-surface; (2) percolation and absorption through the earth-banks, and waste due to leakage; (3) leakage at the lock-gates and sluices; (4) traffic at locks and lifts. Many of these requirements, such as leakage, percolation and absorption, would not apply to a canalised river. Canals are supplied by (1) the flow into the canal of rivers, streams, effluents, and water courses; (2) gravitation and by pumping from reservoirs fed by the rainfall on gathering-grounds; (3) gravitation and by pumping from reservoirs fed by the overflow and surplus water passing down the locks; (4) pumping from deep wells, mines, and rivers; (5) returning to a higher reach-water that has been used in passing traffic.

The flow varies from time to time; when in excess of requirements it is usually passed back by overflow weirs to the river or stream from which it was obtained, but the surplus from one catchment-area may, at times,

be used up in another catchment-area. In some cases, where water is scarce, the purified sewage effluent is used. Water has to be stored to last over the summer months. In some cases, as at Tring summit, water has to be pumped from storage reservoirs. Where water is scarce the overflow, or that passing down by lockage, is collected in small reservoirs on the level of and adjacent to the canal. Supplies from them are used for lower locks, and may also be pumped to the higher reaches to be used again. Where storage reservoirs are not possible and the canal reaches are above the surrounding country, supplies are sometimes got from deep wells, mines, and rivers.

Canals interfere greatly with the normal flow of water. The Grand Junction Canal is supplied with water from the basin of the River Colne at fifteen places. These fifteen canal feeders together drain 226,758 acres that would naturally have supplied the Colne. In some cases, as at Brent, the overflow from a reservoir feeds the river. The case of the Grand Junction Canal will serve to show how greatly a canal modifies the drainage of the district through which it passes.

Levées.—Levées are embankments of earth thrown up to prevent the overflow of streams, or to stop the sea from inundating adjacent lands. They are first known to have been made by the ancient Egyptians and Babylonians. Levées are commonly seen in this country bordering rivers and estuaries that are liable to flood the bordering flats, but it is in other countries that they attain their chief development. By retaining the flood-waters a levée increases the height of the flood, and as the levée system is extended they require to be raised. In the case of the Loire, in France, the original crown of the levée was 15 feet above low water, but it was raised to 21 feet after the flood of 1706. This became too low, and in 1846 an additional 3 feet was added; nevertheless, in 1856 and 1866 the floods surmounted it. According to

General Comstock the bed of the river is not raised, but the increasing height of the flood is due to the extension of the levée system, confining the flood-waters more and more closely. The scheme for the Mississippi required the building of 1,565¼ miles of levée, and 82% of this had been built by 1911. Up to that date 241,040,000 cubic yards of earth embankment had been made, and the complete scheme was expected to require 295 million cubic yards. There is an average annual loss by crevasses, caving in, etc., of 2¼% of the embankments. The area protected from flooding is 26,569 square miles. The rivers Theiss in Hungary, the Po in Italy, and the Loire, have also extensive levée systems.

The length of river channel embanked in Hungary is 3,615 miles, and in addition there are over 6,000 miles of ditches carrying the drainage by culverts through the levées. In Holland about 3,200,000 acres are protected against floods and also 210,000 acres reclaimed from lakes or the sea.

Since a levée prevents the low lands from being flooded, the silt that would normally be deposited on them by flood waters and in time raise their level is carried into the sea, and so denudation is hastened by levées.

Water Supplies.—The earliest piped supplies of water in Britain were established at Southampton, in 1420; Hull, in 1447; Bath, in 1500; Plymouth, in 1590; Rye and Oxford in the seventeenth century; and Pembroke, Haverfordwest, Richmond (Yorks.), and Aberystwyth between 1800 and 1844. In London there were conduits from the local springs, such as Clerkenwell, at an early date, for they are recorded by Stow in 1598; but the first waterworks was founded at London Bridge in 1581, and in 1613 the New River was completed. So late as 1845 a Royal Commission reported that of 50 large provincial towns, only 6 had a good supply. Of the rest, 13 had an indifferent, and

31 a bad supply. In Birmingham only 8,000 out of 40,000 houses, at Norwich one-quarter, and in Newcastle only one-twelfth of the houses had separate supplies; while in Bristol, with 130,000 inhabitants, not more than 5,000 has a piped supply. For the most part people were supplied from stand-pipes or public wells. In 1849 the first report of the General Board of Health stated that it was the common practice to take as sources of supply the nearest river, stream or collection of water, without regard for its quality.

It appears therefore that, in early times, Man's interference with the natural flow of water consisted mainly in taking water from rivers and springs, and that this water would find its way back, in a polluted condition, into the rivers, having suffered some reduction in quantity by evaporation. The size of streams would, therefore, not be markedly interfered with, although the water would be greatly polluted. We have to remember, in this connection, that the population was considerably less, and the quantity of water used per head very much less in early times than is now the case, and that both of these factors kept the amount of water taken from the stream a small one. The "Return as to Water Undertakings in England and Wales," Local Government Board, 1915, concluded (par. 112) that water is now supplied by a piped service to practically every densely populated place in England and Wales. There are still, however, a very large number of rural parishes, some small urban districts and many outlying houses in larger urban districts, that depend for their water on private sources (i.e., wells).

Many towns obtain their water from distant sources. The Manchester supply from Thirlmere is brought 96 miles; the Birmingham supply from the Elan Valley, 80 miles; the Liverpool supply from Vyrnwy, 66 miles, and from Rivington, 24¼ miles; Leicester, Nottingham, Derby, and Sheffield obtain parts of their supplies from the headwaters of the Derwent

(Derbyshire); Bradford receives water from the Nidd Valley; Birkenhead is constructing a pipe-line from the River Alwyn, in N. Wales, and Burnley, Batley, Cardiff, Tynemouth, and the Fylde, all use sources belonging geographically to other catchment areas.

The greater number of the unpiped supplies of the country are provided by wells, most of which derive their water from the subsoil. Springs, streams, rain-water, ditches, lakes, canals, and mines, also supply water. Of the 1,130 boroughs and urban districts in England and Wales, only 29 are without a piped supply, but 67 urban areas have no piped service to more than 50% and 320 to more than 5% of the houses in the district. Of the 12,869 parishes in rural districts, 4,874 have a piped supply. Approximately 62% of the rural parishes are without piped services.

All this water, no matter what its source, is lost to the rivers, for while streams and ditches supply rivers directly, underground supplies find their way into rivers as springs. Pumping from wells reduces the underground water-level, thereby reducing or destroying the springs. Pumping from mines has the same effect, for once the mine cavity is filled, all surplus water will raise the water-level.

In the long run all water-supplies depend upon the rainfall. The average rainfall over England and Wales is about 32 inches per annum. Taking the area of the country at 58,186 square miles, the average total rainfall is 106,408,674,285 tons, or 23,835,543,040,000 gallons. The amount lost by evaporation depends on the soil and on the climate. A porous soil may evaporate from 17 to 22 inches of rain, but there are no sound data for estimating the amount of evaporation from a non-porous soil, though the figure is generally taken at about 12 inches. The local climate also has a marked effect, for where rainfall is high and the atmosphere is generally moist, evaporation will be, naturally, much smaller than in a dry climate.

T. Mellard Reade estimated an average of 13·7 inches evaporated annually from the surface of England and Wales. The remainder of the rainfall, or 18·3 inches, amounts to 68,450,936,960 tons, and may be divided into two parts: that which runs off the surface and that which is absorbed by the ground, to reappear in course of time as springs. The water that runs off sweeps away loose materials into the stream and eventually into the sea, but has little opportunity for dissolving mineral substances, whereas the water that sinks in, re-issues as clear spring water, free from sediment but containing substances dissolved from the rocks through which it has passed. The total amount of rainfall and the proportion that runs off, sinks in, or evaporates, are all modified by Man's activities. These interferences are referred to in the chapter on Climate (page 302).

The quantity of water used by Man, in this country, has risen rapidly, but varies in a remarkable manner in different districts. A Parliamentary Return, issued in 1882, showed that, of five large towns considered, Liverpool distributed only 4½ gallons of water per head per day, while Bradford distributed 25 gallons. A similar return made in 1888 showed a variation from 8 gallons per head distributed in Oldham, to 35 gallons in Edinburgh.

A paper by W. A. Forbes gives the average for urban districts in 1906 as 30 gallons, and H. B. Woodward, in 1910, gives 33 gallons per head per day as the average for the whole country. The Census of 1911 showed the population of England and Wales to be 36,075,269, so that the country uses about 434,526,615,105 gallons of water annually, or about 2½% of the rainfall, after allowing for evaporation. This amount includes water used for domestic and trade purposes, and also that wasted, but in addition water is supplied to feed canals and steam-engines, for hydraulic power and for agriculture. What these further demands on water-supply amount to we do not

know. One item, the loss by evaporation and leakage in the channels of British canals, is estimated at two inches of water per day, i.e., on 1,927 miles of canal of average width (42·5 feet at water-level) the yearly loss of water will be just over 2 million tons, or 448 million gallons. The waste of water at locks is not included. Again, in 1907, railways in England and Wales used over 10,000 million gallons, much of which would come from wells. Breweries were estimated to have used from 10 to 14 thousand million gallons annually during the last seventy years, but this is likely to decrease.

The total amount of underground water supplied by piped services for domestic purposes has been put down as, very roughly, 285 million gallons daily, excluding supplies from surface springs and water from stand-pipes. This is derived from the following geological formations:

	Million gallons daily.
Chalk	139¾
Bunter	71½
Magnesian Limestone	13¼
Superficial Deposits (Recent and Pleistocene)	13
Sandstone in Coal-measures	7
Millstone Grit	6¼
Lower Greensand (Folkestone and Hythe Beds)	6
Keuper Sandstones	4¾
Woolwich and Reading Beds and Thanet Sand	3¼
Carboniferous Limestone	3
Ashdown Sand	2¾
Lincolnshire Limestone	2
Corallian Beds	2
Great Oolite	2
Upper Greensand	1¾
Lias	1¼
Old Red Sandstone	1
Other formations yielding less than 1 million gallons apiece	5¼
Total	285

This quantity amounts to 104,025 million gallons annually. Though not definitely stated, it appears that private wells are not included. The water pumped from underground sources must, therefore, be much greater than the figures given; for example, Clayton Beadle, in 1908, estimated that from 100 to 200 million gallons were taken daily from the London Basin alone by private persons. The quantity of water used by domestic animals is also considerable. In country places they drink river or spring water as a rule, although the supply is sometimes pumped from a well; but in towns they drink piped waters. According to Thresh, cavalry horses are allowed 8 gallons per head and artillery horses 10 gallons daily, and oxen require 6 gallons per head. It is not clear if the water used by animals from piped services is included in " domestic purposes," but probably it is.

H. B. Woodward estimated the water that runs off or that percolates at 10 inches per annum, whereas Mellard Reade estimated it at 18·3 inches. Evidently the data leave much to be desired, but the difference may be due to some extent to Woodward having formed his estimate mainly on data derived from the London Basin. Here we take T. M. Reade's figures because he alone has made elaborate calculations of the quantity of rock carried away in solution by rivers. Now the average amount of solids in solution in water from deep wells and borings is 41·5 grains per gallon (average of 28 analyses), and in spring water only 20·4 grains per gallon (average of 30 analyses). The difference is due to the fact that rain-water, when percolating into the ground, will not descend below the underground water-level (water-table); but on reaching that level will move laterally through the pervious rock until it escapes as a spring. There will be a very slight accession of substances in solution from the stagnant water below the water-level, but such solids as the spring waters contain will be almost wholly

derived from the soluble parts of the soil and the rocks above the water-table. This fact is well illustrated in rock-salt areas, e.g., Northwich, Cheshire, where springs containing a little salt have run for centuries, and yet more than one hundred times as much subsidence has been caused in ten years by the pumping of brine as was caused by natural springs in three centuries, because the only salt removed by springs was that which percolated upwards through the pores of the rocks from below the water-table. The effect of sinking a well, and pumping, is to cause the nearly stagnant water below the water-table to circulate. As it is pumped up, water runs in from round about and a current is produced towards the well. It is often noticed that the water pumped up from a deep well or boring is too highly charged with solids to be palatable or even drinkable, but after a time improves considerably. This is because the stagnant water within the space drained by the well has been pumped out and replaced by fresh water from above.

We see in the case of brine wells (page 149) that pumping may greatly assist denudation, and though less obviously true, the difference in the quantity of solids in solution in deep well water and in spring water points to the same fact.

We have seen that the underground water supplied by piped services for domestic consumption amounts to about 104,025 million gallons annually, with an average of 41·5 grains of solids dissolved in each gallon. The water, therefore, contains about 275,321 tons of solids in solution; whereas had the water been allowed to flow away naturally in springs containing 20·4 grains of solids to the gallon, it would have contained only 135,364 tons altogether. The difference between these figures is 139,957 tons of solids in solution, and this is the additional quantity removed in solution, in piped water supplies through Man's action.

Put in another form, the additional quantity removed is about 72,985 cubic yards per annum.

It has been estimated that a million gallons of water pumped from the chalk contains $1\frac{1}{4}$ tons of chalk in solution, leaving a cavity of 17·6 cubic feet to be filled with water, unless subsidence occurs. In the water annually pumped from the chalk for piped domestic supply only, about 63,761 tons of chalk are dissolved, i.e., 897,753 cubic feet, or 33,250 cubic yards. T. Mellard Reade estimated that the water that reaches the sea, either directly or *via* springs, removes in solution 8,370,630 tons of solids annually from England and Wales.

We shall be probably within the truth in allowing 115 million gallons daily for the water pumped up from private wells in addition to the 285 million gallons of piped supply. Taking the total underground water pumped for water supply at 400 million gallons daily we find, by calculations similar to the above, that the additional amount of rock removed in solution by Man is 196,601 tons, or about 102,524 cubic yards, annually. Rock dissolved in water pumped from mines is additional (see below).

It is unfortunate that we have no data for calculating the total amount of mineral matter removed in solution in water from wells. The quantity of water used for domestic purposes has grown rapidly during the last half-century, and an increasingly large proportion of it has come from deep wells or impounded streams. The change from shallow to deep wells added appreciably to the loss by solution of mineral substances, for a shallow well affects only shallow underground waters that would otherwise find their way into rivers; while deep wells stir up the slowly moving or stagnant waters below the water-table. The increased solution of mineral matter now being effected is therefore of recent date. Although no real estimate of the amount of extra material removed can

be given, we may assume that it will be not less than twelve years' loss at the present rate, or in round numbers say 1,230,000 cubic yards of solids additional to that removed naturally.

Water Pumped from Mines.—The zone of weathering, i.e., the surface belt in which the rocks are affected by atmospheric agents, must be appreciably increased by mining, and by the pumping of water. Dry mines are few; usually they rapidly flood when left to themselves, and during active mining, water is being constantly pumped from them. This produces a circulation of water, derived ultimately from rain, which has a powerful chemical and physical effect on the rocks. The strata mined may be naturally saturated with water which slowly escapes as spring-water; but in deep mines the strata are often found to be dry, partly on account of impervious beds above cutting off supplies of rain-water, and partly because the pressure packs the rock-particles too closely to allow room for much water. The excavations and the shattering of the strata above allow space for water to collect, and this is able to find its way down through the cracked rocks as well as through the shafts. The very impure character of mine waters is itself an indication of the weathering that is taking place below the level normally attacked. When mines are exhausted they become flooded, and if the water has no outlet it becomes saturated with mineral matter and can then exert no further chemical action on the rocks. Sometimes an adit has been made, and if so there is a way for the water to escape, and it continues to circulate instead of stagnating.

Though a very considerable quantity of water is pumped from mines, it is not at present possible to give exact figures. Much of it is pumped into the nearest stream; in other cases it supplies water to work canal locks, after which it will find its way into a river, excepting the part that evaporates or leaks from the

canal back into the rocks below. A rough estimate of the quantity pumped from mines is, however, attempted below (p. 285).

W. J. Henwood gave, in 1843, an instructive account of the quantities of water drained from the Cornish mines in the Gwennap District. There is here a remarkable adit system draining about 5,550,000 acres, with ramifications extending over a length of from 30 to 40 miles, on almost the same plane, at a depth below the surface varying from 12 or 15 fathoms to 70 fathoms in the more elevated regions, with an average depth of from 35 to 40 fathoms (210 to 240 feet). The average size of the adit is 6 feet by $2\frac{1}{2}$ in diameter. More than nine-tenths of the adit is cut in slate; but granite also is passed through, and in many places the adit cuts elvans, and intersects almost every lode and cross-vein in the district. During the period covered by Henwood's observations there were 8 mines working, at depths between 90 and 300 fathoms, and covering a third of the district. Another third was covered by old mines, unworked, and either full of water or partly drained by the working mines. The remaining third was unwrought except for a few, not extensive, trials. This last section is mainly granite and on it are many wells, although in the other sections of the area water for domestic supply is very scarce. The adit contains water drawn from the rocks, lodes, and cross-veins that it intersects, the lodes and cross-veins being very porous and allowing water to descend freely. Into it is also discharged water that has been pumped up from greater depths. The adit was constructed in 1748. Henwood estimates the mean rainfall during sixteen months of 1839-1840 at 1,954 cubic feet per minute on the whole area, of which 310 cubic feet were evaporated, 40 cubic feet flowed off the surface, and 1,475 cubic feet were discharged every minute through the adit. Differently expressed, the average rainfall was 51·12 inches, of which 15·83%

evaporated, 2·03% ran off the surface, 75·42% was discharged by the adit, and 6·65% was unaccounted for.

Theoretically, a perpendicular shaft or well drains an inverted cone, whose apex is the bottom of the shaft; but rocks are laminated, veined and jointed, and these structures offering lines of flow, modify the shape of the cone. Moreover, in mines, levels are being constantly extended, even where shafts are not deepened, although both of these operations go on together in properly worked mines. Some of the mines had not been deepened during the period of Henwood's observations, but three of them had increased considerably during the preceding seven years. Henwood found that deepening the mines from 91 to 136 fathoms (on the average 114), increased the amount of water pumped out. During the five years 1825-1829, in the case of the mines that had not been deepened, the ratio of the water pumped to the rainfall was 1144:1266, but for those which had been deepened it was 1238:1266. Hence the difference ·094, nearly one-tenth of the total, is due to the deepening of the shafts.

Some interesting data relating to the South Staffordshire Coal-field were given by E. B. Marten in 1865. At that time the water raised daily from the mines was 50 millions of gallons (8 million cubic feet), i.e., a stream equal in volume to the River Tame. The country is elevated, divided by a water-parting passing through Rowley, Dudley, Sedgley, and Wolverhampton into two districts. The southern district naturally drains into the Stour and its tributaries, and contains Halesowen, Lye, Cradley, Brierley Hill, Netherton, and Gornal. The northern district, comprising Oldbury, Tipton, Bilston, Darlaston, Willenhall, Wednesfield, Walsall, and Wednesbury, drains into the Tame and its tributaries, except that the extreme northern end of the

area drained into the Saredon, Bentley, Bilston, How, and Crane Brooks. Marten remarks that it is difficult to say how far these drainage areas have been altered, for the canals have absorbed the flow from 25 miles, and the railway cuttings and embankments must have modified many drainage areas; but as the sole supply of water is from the rainfall, it is a safe assumption that the rivers have not increased their flow. Marten found that, over an eighteen month period, the rainfall averaged over 22 inches per annum, so that on the 125 miles of the coal-field the rain would not exceed an average of 108 million gallons daily, to which, however, he adds 4 million gallons daily brought through the pipes from outside the area, making 112 million gallons a day in all. The streams are estimated to discharge about 52 millions, while another 13 millions are diverted into canals, leaving only 47 million gallons for evaporation and percolation. Of the 50 million gallons pumped, about 37 millions flow into canals and 13 millions into streams. Marten remarks that very much of the water finds its way back again into the mines. "The whole surface of the Coal-Field is more or less perforated by pits, or disturbed by mining operations, or divided into catch-water pits by the deposit of spoil-banks, in which the water has to accumulate to considerable depth before it can run off, as the water courses have to be maintained at the old level, although the surrounding ground is depressed. In many places, swags may be found filled with water, which has no means of escape, except by percolation through the bottom."

Marten remarked that in the area around Newcastle-upon-Tyne the water pumped from mines is said to be fifteen times the weight of the coal brought up, and the proportion is still higher in the Forest of Dean; while in South Staffordshire the water weighed only ten times as much as the coal. Evidently the quantities of water pumped, in South Staffordshire, are

not particularly large for the area involved, and, moreover, owing to the fact that in South Staffordshire most of the water pumped is used in the canals, and some of it finds its way back again into the mines, there is less loss of solids than if the water drained into rivers and thence into the sea.

Taking the proportion of rainfall evaporated and absorbed by plants to that which sinks into the ground as 28 to 13, we find that the rainfall supplies only about 15 million gallons daily to the mines. Marten considered that much of the remaining 35 million gallons leaks back again from the canals, but it is difficult to believe that water leaks out of the canals almost as quickly as it is poured in. The sole alternative is that much of the 35 million gallons comes from the underground reservoir formed by the very numerous old coal-workings, and that this is being gradually emptied. Later figures show that pumping had fallen to 9 or 10 million gallons in 1908, indicating that the above hypothesis was correct, and that the reservoir of underground water had been greatly reduced. The marked subsidences in the district also indicate that this is the truer explanation of the source of the water, although there is no doubt that an unknown quantity does leak out of the canals, in spite of efforts to make them water-tight.

In consequence of the uncertain origin of the water pumped and the absence of analyses, we cannot estimate the amount of solids removed in solution from the South Staffordshire coal-field. Marten speaks of the extremely corrosive nature of the water, which caused such rapid decay of the iron of the pumps and rods that in some cases the working barrels have needed to be constructed of brass. Water of similar origin and destructive power from the Coronation Seam, Newbattle Colliery, Newton Grange, in the Edinburgh coal-field, contains 130 grains per gallon total sulphates, in terms of sulphuric acid, nearly one-

third of which is combined with iron as iron sulphate and 91·36 grains per gallon is free sulphuric acid. The sulphates arise from the oxidation of the iron pyrites in coal. This would mean about 219 tons of free acid in 30 million gallons of water, which may be about the daily loss of water from old workings in the South Staffordshire coal-field. Such water would have very considerable solvent powers on whatever it is brought into contact with, whether in a canal, river, or other situation (p. 293).

To estimate the bulk of mineral matter removed in solution from mines by pumping, we require to know the average amount of solids in solution in mine-waters. There are singularly few analyses of such waters. Most of the waters are obviously undrinkable, and in consequence have not been examined. The average of eight analyses of colliery-waters from South Staffordshire, kindly sent me by Mr F. G. Dixon, gave 144,434 grains per gallon of total solids in solution. The average of seven, however, was only 46·526 grains per gallon. The seven contained from 19·0 to 92·1 grains per gallon, while the eighth had no less than 829·771 grains per gallon, largely sodium chloride. Differently expressed, the average of solids in solution in eight samples was ·16346%, but of seven not quite a third of that amount. As the differences are very wide, we shall here take the figures given in the 6th Report of the Royal Commission on River Pollution. The Commission states that unpolluted water from deep wells in Coal-Measures contains, on the average, ·0831% of total solids by weight. Owing to the almost total absence of analyses of mine-waters I have no data for estimating the quantity of solids in solution in waters from mines other than collieries, but I shall assume that, on the average, they contain the same quantity of solids as colliery-waters.

We found above (p. 282) that the water pumped from mines in one coal-field averaged ten times, in

another fifteen, and in a third more than fifteen times the weight of coal raised. This would make the average weight of water pumped from collieries about twelve times the weight of coal raised. As the total weight of coal obtained in the United Kingdom since A.D. 1500 has been estimated at 12,667 million tons, the water pumped will amount to about 152,000 million tons. Even if a mine has been disused for a time and filled with water, the total quantity pumped will not be greatly affected. Once a mine is flooded the stagnant water will dissolve all the mineral matter it is capable of holding in solution, and nothing further happens until pumping is re-commenced. It is true that after a mine is flooded surplus water may overflow through some channel, but normally, the overflow will be fresh water that flows over the stagnant water without much admixture, in the manner explained when discussing salt-mines (p. 148).

For mines other than collieries we have no figures; but as it appears that they are as much troubled with water as coal-mines, we shall assume that they also have yielded 12 tons of water per ton of ore extracted, or a total of about 4,819 million tons of water. Water pumped as brine is omitted, as it contains little in solution except sodium chloride, and that is extracted by the evaporation of the water. A relatively small quantity of salts, however, is left in the concentrated liquors that remain (bittern).

It is to be noticed that in cases where the mine is drained by adits the denudation is the same as if the water were pumped, because the dissolved substances are poured into streams in both cases.

The average spring-water contains 20·4 grains per gallon, or ·02914% of total solids, and we may assume that the difference in solid contents between mine-water and spring-water, or ·05396% of the weight of water pumped, is the excess of solids removed in solution by Man's activities.

The coal raised in the United Kingdom in 1913 was 287,430,473 tons, and the water pumped to obtain it would contain, on the above reasoning, 91,620 cubic yards excess over an equal quantity of spring-water, assuming that the solids had a specific gravity of 2·7. Taking the total amount of coal excavated in the United Kingdom since the earliest times to be 12,667,000,000 tons (p. 24), a similar calculation shows that in the water pumped to obtain that output there would be 40,392,000 cubic yards of solids more than in the same quantity of average spring-water.

Owing to the almost total absence of analyses of mine-waters I have no data for estimating the quantity of solids in solution in mines other than collieries. I shall therefore assume that their waters are similar as regards total solution to those from collieries. On this assumption we find that the 4,819 million tons of water would contain 1,280,000 cubic yards of solids more than an equal volume of spring-water. Adding this to the figure for coal-mines we find that Man has removed in solution in water pumped from mines about 41,672,000 cubic yards in excess over the quantity that would have been removed naturally.

Total Solids Removed in Solution by Man.—Adding together the excess of solids removed in solution from mines and that removed from deep wells (p. 279), we find that the total solids removed in solution by human agency is about 42,902,000 or say 43 million cubic yards.

Modifications in Natural Drainage.—We have already (p. 273) discussed the effect of engineering operations on the underground flow of water; the "taming" of streams (p. 261) and the improvement of rivers for navigation. We have now to notice some other modifications of surface-drainage caused by human activities.

In places where the rocks are highly porous, as, for example, the outcrops of the Bunter and Chalk

formations, the effect of pumping from wells is sometimes to dry up small rivers. In Chalk and Bunter country there is a great scarcity of streams. The valleys are deep with rounded bottoms, many of them dry, and they were formed during a cold period when the ground was frozen (see C. Reid), as now is the case in Siberia. Melting snow and ice were unable to sink into the frozen subsoil and, forming torrents, dug out the " combes," as these valleys are called in the Chalk districts. With a change in the climate the subsoil thawed, and water, whether from melting snow or from rain, no longer flowed over the surface, but, sinking at once into the porous rock below, was unable to denude the surface, and the combes remain practically unaltered to the present day. The base of the Chalk is marly and impervious, and water sinking into the rock eventually reaches a marly stratum. The chalk above is saturated to some definite level, depending on local circumstances, called the water-table, below which surface water cannot penetrate, but flows over the surface of saturation to the nearest outlet. Owing to the dip of the rocks towards the centre of the basin, whether it be the London or the Hampshire Basin, it may happen that the water-table is above the floor of some of the valleys; when this happens springs appear and a stream flows along the valley floor. Precisely the same thing happens in the thick sandstones and conglomerates comprising the Bunter formation, which covers a large area in England, for example Sherwood Forest and Cannock Chase. The result of pumping being to lower the water-table, this may sink below a valley-floor, whereupon the springs dry up and the headwaters of the stream retreat down the valley until the new level of saturation is reached.

Cases have been examined by Mr Urban A. Smith, in Hertfordshire, and brought before the notice of the Royal Commission on Metropolitan Water Supply. He stated, in 1893, that during the previous twenty

years, all three heads of the River Colne had shrunk; the River Gade now rose 2 miles farther down its valley, the Bulbourne about 1½ miles, the Chess about 2 miles, and the Ver about 5 or 6 miles, the Mimram ½ mile, the Beane several miles, and other rivers similarly had shrunk (also see A. M. Brown). The same thing has been noticed near Nottingham, in the Bunter country. The case of the Bulbourne is particularly interesting, because it has risen north of the Chiltern Hills within historic times, whereas the upper part of its former course now forms a so-called " wind-gap " (dry gap) in the Chilterns and has led to mistakes as to its age.

The drying up of streams in this manner is the result of pumping for water-supplies. In many places the effect of pumping in lowering the water-table will have a considerable effect on land-drainage, for, if the water-table is lowered, there is an increased tendency for rainwater to sink in instead of running off.

Although irrigation is scarcely practised in Britain, engineering works of very similar character to those of irrigated countries are constructed in connexion with water-supplies, whether intended for drinking purposes, for the supply of canals, or for driving machinery. The collection of the water by damming streams or sinking wells is carried out as if for irrigation.

The proportion of the area of Britain from which the drainage is collected is considerable but unknown. The collecting-areas for drinking-water are situated on sparsely inhabited moorlands, such as the Pennines, Dartmoor, Charnwood Forest, Wales and the Lake District. But in addition to these supplies of pure water a great deal is collected to feed canals or drive machinery; and, since purity is not essential in such cases, these catchment areas frequently comprise inhabited districts. Moreover, the rain falling over towns runs off roofs and pavements into sewers, to that extent robbing the rivers of their natural supplies.

The areas in England and Wales from which water is impounded by Man have been reduced by the author on maps on the scale of 10 miles to one inch, and the Plate facing p. 301 is a reproduction of a piece of the maps. In the relatively small area shown, 40 by 70 miles, there are no less than 80 different areas that have been taken from the natural catchments of rivers and the waters turned into artificial channels. A few of these channels are also indicated on the map. The areas shown are probably far from being all that exist. It is difficult to find the boundaries of many of the areas, which are in numerous cases only to be ascertained from maps accompanying Parliamentary Bills. The Map, however, will give some idea of the extent to which the natural drainage has been altered. The water that is collected may be conducted through reservoirs and filtering appliances to pipes, and then distributed in some town many miles away. After use it passes into the drains and usually undergoes some purifying process before the residue that has escaped evaporation is poured into a river, canal, or the sea. If the water collected, or the sewage effluent, is put into a canal, it will find its way to the sea after having actuated lock-gates. It is interesting to notice that water taken from one catchment area, after use, not uncommonly enters the sea from another catchment area. Thus the waters of the Vyrnwy belong to the Severn system of drainage, but have been diverted to Liverpool, where they enter the Irish Sea instead of the Bristol Channel; again, the water of Lake Thirlmere, instead of reaching the sea at Workington, Cumberland, are conducted to Manchester and finally enter the Mersey.

Water from a catchment area is made to run into a reservoir, where it deposits any detritus and issues as apparently clean water, even though it is impure. Almost always compensation water has to be supplied to the river, robbed of part of its natural supply, other-

wise, in dry weather, the water might fall too low to preserve the fish, or to work mill-wheels on its banks. Left to itself, the amount of water in a river will vary greatly at different seasons, and unless compensated the quantity taken, although scarcely noticeable in time of flood, might be the whole supply in the dry season. During rainy periods the reservoir holds up the water falling within its catchment-area and helps to prevent floods. On the other hand, in dry weather, by turning into the river a suitable amount of water from the reservoir, the river is prevented from falling so low as it would do if left to Nature.

All detrital matter that the natural river would sweep down to its flood plain, or to the sea, is deposited in the reservoirs, where it produces deltaic fans, as in natural lakes. To prevent the reservoir from silting up, it is necessary to clean it out occasionally and pile up the silt and stones on the land. T. Mellard Reade has given some interesting measurements of a delta situated in the Pennines, formed in the Rivington Reservoir, belonging to the Liverpool Corporation. During the twenty-seven years from 1855, the date of construction, to 1883, the sediment stopped by the reservoir formed a delta with an estimated volume of 6,306 cubic yards. The drainage area supplying the sediment was 1·176 square miles.

As reservoirs are numerous and the number is rapidly increasing, the effect on denudation must be considerable. There are 128 reservoirs in England and Wales for the supply of canals alone. Above the reservoirs, rain and floods will act as before Man interfered; but the detritus washed away will be intercepted before it reaches either the sea or the flood-plain, where normally it would be deposited. In the lower reaches, below the reservoir, the stream will run far more steadily than before, and is free from sediment, unless it is obliged to pick up a new burden below the dam.

The " taming " of streams, as it has been called,

greatly diminishes their eroding power. It has always been difficult to understand the amount of erosion accomplished by rivers when one watches the seemingly small effect of even a torrential stream in its ordinary condition. It is beginning to be realised that a great deal of erosion is performed in a cataclysmic manner after exceptional rainstorms. A cloud-burst may, in half an hour, dig a trench that twenty years of normal rainflow would have scarcely commenced.

A relatively small instance of this came under the author's notice. In June, 1910, a sudden hailstorm occurred at Little Kingshill, near Great Missenden, Buckinghamshire. The surface of the land there is a dissected plateau covered with clay-with-flints. The slopes of the deep valleys are mantled with downwash resting on the chalk, which everywhere underlies the superficial deposits. The heavy hail struck a field on the plateau and washed away the clay and stones in its narrow path until the margin of the valley was reached. Here the sudden increase of slope caused the torrent to dig a trench about 160 yards long, a foot wide at the top of the slope and much more at the bottom, and on the average 2 to $2\frac{1}{2}$ feet deep. The detritus was deposited at the bottom of the valley. One part of the trench was 5 feet in depth and the time occupied in its formation was from 1 to $1\frac{1}{2}$ hours. This case is probably an instance of ravine-formation such as we have described as occurring in countries denuded of woods by agricultural operations (p. 308).

Reservoirs offer protection to the valleys below them, for a flood exhausts itself in filling up a reservoir and dumping there the burden of stones, or it may be trees, which are the chief weapons of attack. The reservoir may later overflow, but even then the stream below has had time to rid itself of its own surplus water before that from above reaches it, and so a flood is prevented or reduced. Moreover, the water overflowing the reservoir is less than the original flood by

the quantity needed to fill the reservoir, and the water has lost most of its destructive powers with its detrital burden.

It may happen exceptionally, however, that the heavy flow of water kept up by a reservoir after a flood has passed coincides with a flood-crest at the mouth of a tributary below, in which case it will actually increase the flood below the entrance of the tributary.

The collection of water into reservoirs, i.e., artificial lakes, and the " taming " of rivers tend to prevent floods, in opposition to the effect produced by the clearing of forests.

Pollution of Streams.—Pollution of streams is largely a thing of the past, but the Reports of the Rivers Pollution Commission (1863), published from 1870-74, give a lurid account of the condition of British streams and rivers at that period. In colliery districts the " slack," long regarded as waste and often burnt, was sometimes tipped into a stream; but at the time of the Commission it was, to a great extent, washed, to free it from shale, which was allowed to silt up the rivers and cause floods, as below Staveley and Chesterfield, Derbyshire. In some cases the water pumped from collieries has been useful as a purifying agent, as in the case of the River Taff, which, up to about 1860, received the unpurified sewage of Merthyr Tydfil, but was much improved after mingling with the ferruginous waters from Llancaiach Colliery; because the iron precipitated the sewage to a considerable extent.

Of waters from other mining districts those from the lead " jiggins " were the most objectionable. In flood times the mud was spread over alluvial flats near Aberystwyth, Hexham, Matlock, and the upper tributary valleys of the Tees, Wear, and Clyde. At Aberystwyth and Machynlleth, the vegetation being killed, the soil, unprotected by grass, was washed away.

Of metal trades the most damage was done by the Iron and Steel Wire, Tinplate and Galvanising Works, which employed sulphuric and hydrochloric acids to cleanse the metal. The liquids were poured into the sewers, often suddenly and in volume, and being very acid dissolved mortar in the linings of the sewers. Brass foundries produced the same effect, but to a much less extent.

The eroding effect of acids and other substances in solution in streams, was strikingly brought out in the 6th Report of the Commission. Mr A. E. Fletcher estimated that in 1870 the free hydrochloric acid annually run to waste in the United Kingdom was 371,133 tons of commercial acid, equivalent to 111,400 tons of pure acid (HCl). This amounted to 45·5% of the quantity made in the country.

The worst case of pollution from alkali works at that time was the Sankey Brook near St Helens, Lancashire, which could be smelt at a distance of from one to two miles. The brook supplied the Sankey Canal, and it is recorded that the canal-water was so corrosive that the lock-gates had to be constructed entirely of wood. The canal received from one firm alone 500,000 gallons of 1% hydrochloric acid which destroyed the mortar, ironwork, and even the sandstone banks. Yet about twenty-five years previously, according to Mr Atherton Selby, the Sankey Brook, that fed the canal, was fit for domestic use and contained fish.

Arsenic, in the form of arseniate of sodium, formerly escaped from dye-works. At the time of the Commission's investigation 400,000 tons of pyrites were annually imported and burnt for the manufacture of sulphuric acid. At a moderate computation this pyrites contained 1,600 tons of arsenic, a large proportion of which found its way into the rivers and streams. In addition, the soda-ash process, introduced into Britain in 1824, gave rise to the heaps of

alkali-waste that are so noticeable near St Helens, Widnes, Newcastle-on-Tyne, and in South Staffordshire (p. 209). In course of time weathering processes render them harmless; but for years the heaps give off sulphuretted hydrogen gas (H_2S), and rain falling on them carries away immense quantities of salts in solution. The quantity of sulphuretted hydrogen freed from Leblanc alkali-waste may be realised to some extent when we find that the heaps of waste at Widnes alone, estimated by Mr E. Rhodes at 10 million tons, contained originally about 15% of sulphur, whereas the weathered waste contains only about ·938%. From Widnes alone, therefore, about 1,400,000 tons of sulphur, mainly in the form of sulphuretted hydrogen, has found its way into the streams, either directly or *via* the rainfall.

Other chemicals also were poured into the rivers and canals from the alkali and other works. The manganese dioxide used in the country at that period was about 54,000 tons annually, and this nearly all found its way into streams in the form of manganese chloride.

At one time a great deal of sulphuric acid escaped into the atmosphere from works in the alkali-districts, but this is no longer the case.

From soap-works, glycerine and common salt were the chief polluting agents, and at that time one firm at Widnes, alone ran about 5 tons of glycerine (from 100 tons of fat) into the Mersey every week. Other trades were responsible for a variety of noxious substances.

In the Fourth Report, dated 1872, it is stated that the Glasgow sewage entered the Clyde. The water supply of the city was 27 million gallons daily, or more than half the natural flow of the river (50 million gallons upwards). A result of deepening the river, from a few to 24 feet at high-water, was to lessen the velocity, with the result that the sewage, entering in

the midst of the city, reached Govan ferry, $2\frac{1}{2}$ miles downstream, in a week and Dumbarton in a month and so had time to putrefy.

Waters polluted by sewage are hard waters.

In the First Report, dated 1870, there is a detailed account of the pollution of the River Irwell, which separates Manchester from Salford. The Irwell basin has an area of 199,520 acres and the population at that time was 1,014,569, or 3,254·4 persons per square mile. The factories were often within 200 or 300 yards of one another and 10,500 factories and works of all kinds were supplied from the waterworks of Manchester, Bolton, Bury, Bacup, Heywood, and Oldham. The Irwell and its tributaries were in the condition of common sewers, and as an illustration of its condition the Report prints a facsimile of a page written in Irwell water instead of ink. At Throstlenest Weir, below Manchester, at 5 a.m. on 21st July, 1869, the Commission noted its condition to be as follows: "We saw the whole water of the River *Irwell*, there 46 yards wide, caked over with a thick scum of dirty froth, looking like a solid sooty crusted surface. Through this scum, here and there, at intervals of six and eight yards, heavy bursts of bubbles were continually breaking, evidently rising from the muddy bottom; and wherever a yard or two of scum was cleared away, the whole surface was seen shimmering and sparkling with a continual effervescence of smaller bubbles rising from various depths in the midst of the water, showing that the whole river was fermenting and generating gas. The air was filled with the stench of this gaseous emanation many yards away. The temperature of the water was 76° Fahr., and that of the air 54°."

In addition to sewage there was pollution by dye, print, bleach, chemical, woollen and silk works, tanneries and paper-mills. One print-works alone was estimated to pour into the river 500 million gallons of water annually, containing about 650 tons of solid

matter in solution and 220 tons in suspension. The works employed 250 hands and was exceptionally careful.

At a thousand places along the Irwell and its tributaries mineral matter, much of it earthy waste, was thrown in. Many thousand tons of coal were burnt on its banks, and the ashes, roughly 12½% of the coal, were generally thrown into the stream. Between Albert Bridge and Throstlenest Weir the bed of the Irwell had risen, on the average, 1½ inches per annum since 1862. Elsewhere there were great shoals and obstructions.

The Reports of the Commission led to legislation, which has to a considerable extent cured the evil. The period of extreme pollution seems to have been a short one, for the Report states that many people gave evidence that in their early days they fished in many places where at the date of the Report fish could not live.

The different kinds of substances polluting rivers have widely different effects on the capacity of the stream to erode, and to carry a burden in solution or suspension. Certain substances, such as soap, have an emulsifying action, and enable water to retain solid matter in suspension for a considerably increased period as compared with natural river-water. On the other hand, salts in solution cause suspended solids to be deposited. Briefly, we may say that substances which are electrolytes, i.e., which permit an electric current to pass through their solutions, cause solids in suspension to be deposited, while non-electrolytes tend to retain them in suspension. Both classes of substances will often be present together in polluted waters, in some cases one or the other type will greatly preponderate. There are as yet no data to enable one to estimate the nett effect on the turbidity of streams of the various kinds of pollution. In some cases the effect will be to carry the silt farther out to sea, before

the salt-water causes it to be deposited, than would naturally be the case. In other cases, substances in solution may cause deposition on the river bed and tend to choke up the stream. The complexity of the problem may be illustrated by the case of pollution from a soap-works. Formerly the chief substances added to the stream were glycerine and salt; but now glycerine is too valuable to be allowed to escape, and salt, being an electrolyte, has the opposite effect to soap on turbidity. Hence the effect of pollution by a soap-works is probably the opposite to what one might expect to be the case.

Soap, however, finds its way into the rivers, though not from soap-works. The quantity used in the United Kingdom in 1907 was 352,750 tons, the whole of which, after use, would presumably find its way into the sewers. In the presence of a solution of soap all dissolved calcium salts, which are present more or less abundantly in all natural waters, are precipitated. Probably before a river reaches the sea all the soap it carried has been decomposed and replaced by organic salts of calcium, which are deposited on the bed together with entangled sediment; and solutions of sodium sluphate and perhaps chloride, according to the soluble salt of calcium originally present. Potash salts derived from soft soap replace sodium salts in part.

Mr H. S. Williams, in his "Elements of the Geological Time-Scale," says: "It may be a query worth considering whether the estimates based upon the examination of the amount of suspended and dissolved matter in river water are not likely to err in the direction of too small amount of matter by reason of the abnormal precipitation along the course of the river incident to the presence of salts and acids put into the river by Man. If the rate of the Po were taken the length of time [of the Geological Time-Scale] would be 73,000,000 of years instead of 680,000,000."

The practical effect of colloid organic matters is said, by A. Findlay, to be illustrated by the Rivers Mississippi, Nile and Ohio. The two former are turbid, and contain much organic colloidal matter washed in with clay or soil, but this is deposited in bars and deltas. The Ohio is clear, except in flood time, owing to the absence of colloidal matter and the presence of lime and other salts. F. W. Clarke, in the "Data of Geochemistry," states that organic matter in natural water forms a flucculent precipitate with iron salts, carrying down, mechanically enclosed, the finest sediment.

Now that the pollution of rivers has been greatly reduced the effect on the turbidity of streams has been greatly minimised, but during the period when chemicals and sewage were allowed to flow into the rivers they probably exercised an appreciable effect on the rate of denudation.

The rivers became highly polluted probably between 1830 and 1840 and Parliament came to the rescue and suppressed much of the pollution about 1880. Hence the period of extreme pollution was probably limited to about thirty or forty years. After that time means were found to purify the streams and in many cases uses were found for the waste products.

Nett Effect on Denudation of Man's Interference with the Circulation of Water.—It is doubtful to what extent Man's interference with the flow of water affects denudation. The material removed in solution is certainly increased (p. 286). Land drainage tends to prevent flooding by offering an easy escape for water to the sea; but agricultural operations tend to promote floods by causing the rain to run off the surface more rapidly than was the case under natural conditions. The collection of water into reservoirs and the doling out of compensation water to the streams would appear to destroy their power of erosion; for a stream erodes its bed by sudden rushes of water after rainstorms and

under the new conditions the streams have a uniform flow. Nevertheless we must remember that the bulk of stream erosion is caused by mountain torrents, while reservoirs are placed below the torrents, collecting the water after it has exercised much of its erosive power. This is shown by the typical case of Rivington (p. 290).

Mr G. W. Lamplugh concludes (" The Taming of Streams ") that there is an increased removal of fine material from the land to the sea, but on the other hand, coarse *débris* pushed along the bottom of the stream is artificially removed and is very generally used in raising the flood banks. He concludes that the natural deepening of valleys is usually checked and in many places stopped, but nevertheless the degradation of the land surface as a whole may be accelerated. The main tendency is to flatten the land contours.

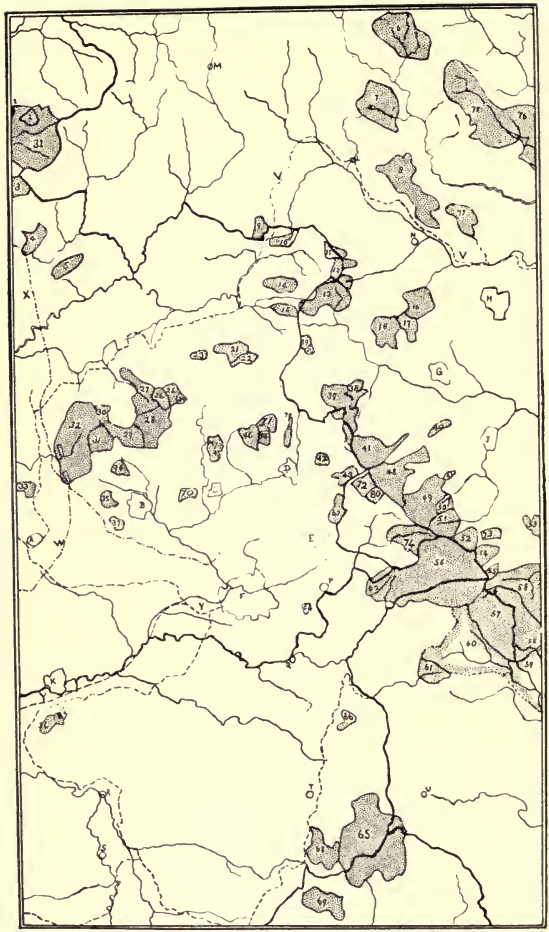
Effect of Subsidence on Drainage.—The effect of subsidence on drainage has been referred to in the chapter on Subsidence (p. 140). We have not sufficient data to estimate the extent of alteration so caused, but in mining districts it is considerable. One result is to lower the gradient of streams, thereby rendering them more sluggish and less capable of carrying sediment to the sea. In low-lying districts swamps are frequently formed, e.g., round Wigan. In some cases the direction of drainage may be altered and waters find a new course to the sea.

Explanation of Map of part of the Pennine Chain to show the areas from which the water that runs off the surface is impounded by Man for water-supply, or the use of canals, etc.

The shaded areas are the impounded districts; those partly shaded being areas about to be used. More areas have been taken by Man than are shown, but it has not been possible to fix the sites of them all on a map.

Unshaded areas are towns; they are indicated by letters, as are also certain canals and pipe-lines. The numbers refer to the town or canal that uses the water collected.

1 = Lancaster
2 = Lancaster
3 = The Fylde
4 = Preston
5 = Preston
6 = Bradford
7 = Bradford
8 = Bradford
9 = Leeds and Liverpool Canal
10 = Leeds and Liverpool Canal
11 = Colne
12 = Keighley
13 = Halifax
14 = Nelson
15 = Heywood
16 = Bradford
17 = Halifax
18 = Halifax
19 =
20 =
21 = Bury
22 = Bury
23 = Accrington
24 = Bury
25 = Bury
26 = Bury
27 = Blackburn
28 = Bolton
29 = Bolton
30 = Darwen
31 = Bolton
32 = Liverpool
33 = Leeds and Liverpool Canal
34 = Bolton
35 = Bolton
36 = Warrington
37 = Bolton
38 =
39 = Rochdale Canal
40 =
41 =
42 = Bury
43 = Oldham
44 = Bury
45 = Bury
46 = Heywood
47 = Huddersfield
48 = Wakefield
49 = Huddersfield
50 =
51 = Holme
52 = Batley
53 = Barnsley



MAP OF PART OF THE PENNINES, SHOWING AREAS TAKEN BY MAN FOR WATER SUPPLY.

(Based upon the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.)

54 = Dewsbury
55 = Dewsbury
56 = Manchester
57 = Sheffield
58 = Sheffield
59 =
60 = Derwent Valley
61 =
62 = Ashton-under-Lyne
63 = Oldham
64 =
65 =
66 =
67 = Warrington
68 =
69 =
70 =
71 = Rochdale
72 = Oldham
73 = Holme
74 =
75 = Leeds
76 = Leeds
77 = Shipley
78 = Rochdale
79 = Rochdale
80 = Oldham
81 =
A = Wigan
B = Bolton
C = Bury
D = Rochdale
E = Oldham
F = Manchester
G = Halifax
H = Bradford
J = Huddersfield
K = Warrington
L = Skipton
M = Settle
N = Keighley
P = Ashton
Q = Stockport
R = Northwich
S = Winsford
T = Macclesfield
U = Buxton
V = Leeds and Liverpool Canal
W = Liverpool Pipe-line
X = Manchester Pipe-line from Thirlmere
Y = Manchester Ship Canal

CHAPTER IX

CLIMATE AND SCENERY

THE atmosphere is composed of three chief constituents: oxygen, nitrogen, and argon, with a variety of other gases present, some only as traces; krypton, xenon, helium, and neon being always present in definite though small quantities, and others varying more or less in their amount. Of the variable constituents, carbon dioxide and water are by far the most important, but there are also present ozone, hydrogen peroxide, etc. The water present varies widely in amount, but the carbon dioxide only slightly, and except in towns and some other places it forms about 3 parts in 10,000 of air by volume. This apparently small quantity is really of vital importance, for it forms an essential foodstuff of green plants, and therefore indirectly of all animals, since every animal, directly or indirectly, lives on green plants. In addition carbon dioxide has a powerful effect on climate, because it has the property of absorbing heat reflected from the ground which would otherwise be radiated into space. Arrhenius thought that if the amount of carbon dioxide in the air were increased threefold, the temperature of the Arctic regions would rise by 8° or 9° C., and similarly a reduction to about half or a third of its present amount might produce a glacial period. T. C. Chamberlin has worked out on these lines an explanation of the recurring glacial and tropical periods that are known to have occurred in the past. He thinks that the Permian glaciation was

a consequence of the removal from the atmosphere of the vast mass of carbon locked up by animals and plants, in the form of limestone and coal, during the Carboniferous period. This leads us to speculate on the probable effect on climate when the carbon of coal and petroleum is restored to the atmosphere as carbon dioxide by combustion.

The atmosphere loses carbon dioxide mainly (1) by the growth of green plants, which decompose it into carbon and oxygen and retain the former element; (2) by the carbonation of minerals in the earth's crust. This latter action usually takes the form of replacing the silicates in such minerals as felspar, hornblende and augite by carbonates. An additional quantity of carbon dioxide may combine with the carbonates of calcium and magnesium, thereby forming bicarbonates, which are removable in solution by rain-water.

On the other hand the atmosphere gains carbon dioxide (1) by the respiration of all animals and plants and by the decay of their dead bodies; (2) by the fact that when the normal carbonates of calcium and magnesium are reproduced by living beings such as corals, molluscs, and nullipores, which require them to build up their skeletons, half the carbon dioxide contained in the bicarbonates dissolved in sea-water is liberated; (3) by emission from volcanoes.

At the present time coal does not seem to be forming anywhere, and although peat is growing in some countries it is decaying in others, e.g., Great Britain. This means that, no matter how much carbon is abstracted by green plants from the air, it is all restored on the death and decay of the plants, and of the animals and parasitic plants which all, directly or indirectly, derive their substance from green plants. Hence the nett result on the atmosphere of animal and vegetable activities at the present time appears to be approximately nil. E. H. Cook calculated that the action of green plants in decomposing carbon dioxide

is sufficient to remove all additions of the gas to the air, but he appears to have overlooked the fact that dead land organisms decompose and return their constituents to the air and soil.

Besides the enormous additions of carbon dioxide to the atmosphere made by the combustion of burning coal, lignite, and peat, there are additional sources of increase due to Man. In clearing the land for cultivation, enormous areas of forest are turned into arable or pastoral land. This must considerably diminish the total quantity of green-leaf surface, for it seems obvious that in a forest, where the land bears not only the trees with their bushes of leaves, but also the undergrowth, as well as the mosses and lichens attached to the stems, there will be more green-leaf surface per acre than in a field of grass or crops, especially when a part of the ground is always fallow. The difference between the quantity of carbon locked up in the vegetation after clearing and that in the forest and undergrowth that formerly covered the same ground, is an addition to the carbon dioxide in the atmosphere, for if the tree is burnt it goes back directly into the air, but if made use of as timber the return is only delayed for a relatively short period until the timber decays or is burnt.

Man has also interfered with animal life, and it might seem at first sight that the carbon dioxide given off by the respiration and decay of the 1,600 millions of human beings on the earth is a new addition to the supply; but, although we cannot say just what changes in the animal population have been brought about by Man, it appears to be the case that the earth carries the largest mass of living creatures that it can support (hence the Struggle for Existence), and therefore the increase in the population of human and domestic animals probably coincides with the destruction of an equal weight of other animals, otherwise there would be a scarcity of food. On the whole the destruction

of forests and the consequent reduction in the quantity of plant-life will lead to a corresponding reduction in the quantity of animal life dependent on it for food.

Assuming T. C. Chamberlin's working hypothesis, referred to above, is correct, and that the Permian glacial epoch was caused by the removal of carbon from the atmosphere by living beings during the Carboniferous period, we may reasonably consider the result of a reversal of the process.

The world's annual consumption of coal now exceeds 1,000 million tons. Taking the average percentage of carbon in coal as 84, and supposing that 4% remains unburnt in the ash, then 800 million tons of carbon are annually burnt to make 2,933 million tons of carbon dioxide, which passes into the atmosphere. This also receives a considerable amount of carbon dioxide from burnt petroleum. The first petroleum well was sunk in 1859, in the Appalachian Mountains. The first Russian well was sunk in 1871 at Baku. In 1908 the world's output was about 40 million tons, and the total output of petroleum, up to 1908 inclusive, was 446,319,514 tons. The average percentage of carbon in petroleum is 86, so that the quantity of carbon dioxide added to the atmosphere by burning the above amount of oil is 1,209,079,563 tons. In reality this is far below the true amount, for there has been an appalling waste of oil and natural gas by fires at the wells, and the real figure is probably fully 2,000 million tons of carbon dioxide. At three parts in 10,000 the carbon dioxide in the atmosphere amounts to about 2,200,000 million tons, equivalent to 600,000 million tons of carbon. At the present rate of consumption of coal and oil, which adds some 840 million tons of carbon to the air annually, it is clear that in about seven hundred years the carbon dioxide in the air would be doubled, and in one thousand four hundred years trebled, bringing about the warm climate foretold by Arrhenius, unless

there are means of removal as yet unknown. Other effects of such an increase of carbon dioxide would be that (1) by the law of partial pressures, when the percentage of the gas is increased, the solubility in water is increased in like proportion, so that when the amount had been doubled the solubility in water would be doubled, and rain would dissolve twice as much of the gas as at present, and its chemical action on soils and rocks would consequently be increased. This action would be aided by the increased rainfall following on the rise of temperature, for more carbon dioxide in the air means a more humid climate. Chemical denudation would therefore be increased and more calcium bicarbonate would be swept into the seas. (2) Animals and plants building their skeletons of calcium carbonate would probably be encouraged to multiply by the increased supply of raw material, and the formation of limestone would receive a stimulus. (3) There would be a physiological effect on air-breathing creatures. Presumably, green plants would be stimulated by the warmth and by the increased food supply, and would grow more luxuriantly; on the other hand the higher animals would probably be injuriously affected, although they would doubtless have been getting gradually acclimatised to the new conditions.

The effect of vegetation on climate has been described with great fullness by G. B. Marsh, whose book, " The Earth as Modified by Human Action," is mainly devoted to the meteorological effect of forests and the results of their destruction by Man. This branch of the subject will therefore be treated very briefly.

Marsh gave reasons for thinking that the habitable earth was in all regions, with few exceptions, covered by forests when it first became the home of Man. He thought that even many parts of the African and Arabian deserts would soon be forest-covered if Man

and his domestic animals, especially the camel, were banished. Young trees sprout plentifully round the wells of the desert, and groves and shrubs spring up in their shade, but the camels destroy them as fast as they grow. Given a few years they would form groves that would gradually extend over the desert.

It seems to be established that forests tend to mitigate extremes of temperature, humidity and draught. They protect the district to leeward from winds; e.g., the felling of woods on the west coast of Jutland has exposed the soil not only to drifting sand-dunes, but also to winds that have had a sensible deteriorating effect on the peninsula.

It is well known that forests maintain springs in permanent and regular flow, and consequently the streams fed by springs. Mosses and fungi growing on trees, and the dead leaves on the ground, act as sponges, absorbing the rain and giving it out gradually. The destruction of forests leads to the drying up of springs, and causes the streams to fail in dry seasons and inundate the country in wet weather. As it is during floods that streams do almost all of their mechanical erosion and transportation, destruction of forests leads to increased denudation. A striking instance is offered by the Ardéche, in France. This river drains a little less than 938 square miles, and is about 75 miles long in a straight line from source to termination. Originally the basin was richly wooded, but a large part of the forest has been destroyed, and it is to this cause that the disastrous floods are assigned. When the river is low it is fordable almost everywhere, but in flood-time it has been known to rise to a height of more than 60 feet at the Pont d'Arc, a natural arch below the junction with all the more important tributaries. During the great inundation of 1857 the quantity of water passing the Pont d'Arc, after allowing 30% for solid matter transported and for irregularity of flow, was estimated

at 8,845 cubic yards per second. On such occasions this little river carries more water in a day than the daily average flow of the Nile with its million square miles of drainage. Such inundations do enormous damage, and in 1843 it was estimated that, up to that date, 70,000 acres of good land had been covered with sand and gravel. Since the fifteenth century, and even since the eighteenth, there has been a great falling off in the wealth and population of Upper Provence and Dauphiny.

Woeikof has given a remarkable account of the effects of deforestation in Russia, and particularly of the formation of ravines. He says that ravines do not form either in forests or on prairies, vegetation acting as a preventive. Man assists destructive agencies by cultivating the soil, for cultivated plants are not as a rule so deeply rooted as wild ones, and, moreover, there is an absence of mosses, lichens, and dried leaves to hold the rain as in a sponge. The ravines formed in the northern and central plains of Russia are not so large as those of the mountainous districts of the French Alps and Cevennes, but their number is far greater, the Russian ravines being perhaps 1,000 times as numerous as the French ones, and the area subject to destruction is thousands of times greater than that in France. On the 52 kilometres of road from Ardatov to Alatyr, Simbirsk Government, there were, in 1862, two and in 1892, 46 bridges, the new ones spanning newly formed ravines. Again, on the left bank of the Dniestr, between the towns of Soroki and Mohilev, there are frequently ravines in the chalk only 10 to 15 metres apart. As the river is embanked and the slope of the ravines very steep these carry a great quantity of stones and gravel, which encumber the beds and oblige the engineers to raise them. Not only is ravine formation considerable in a great part of the Russian plain, especially the most populous parts of the region of the "black earth," but

the formation of alluvium and cones of dejection is equally great. In the district of Lokhvitsa, Poltava Government, it is found, on digging wells in the ravines, that a deposit, 12 to 17 metres thick, of sandy clay has accumulated beneath the soil. Moreover, the soil and subsoil in much of the " black earth " region is of average permeability, and there is a feeble penetration of water so long as the ravine has not made great progress. When, however, this has happened, the subjacent beds are laid bare and are often found to consist of sand or limestone with great crevasses. In the district of Syzran, Simbirsk Government, where the rivers and ravines have very steep slopes, a very friable grit crops out a little below the soil, with the result that the ravines carry great quantities of sand onto the fields, and form true land dunes. The formation of ravines greatly lowers the water-table and also drains ponds. Ravines also frequently alter the hydrographic basins by enabling one river to capture another.

Woeikof remarks that although the material carried by rivers has often been measured and the average erosion calculated, too little attention has been paid to the modifications caused by the presence or absence of vegetation. In well wooded or marshy countries, peaty matter frequently accumulates, rendered brown by a solution of tannic acid, and free from suspended matter. These " blackwaters " are well known in the Amazon basin, where they give a name to one of the main tributaries, Rio Negro, and they are also frequent in North Russia. Under such conditions the amount of material carried by the streams is much less than is carried by rivers traversing deforested country and a great spread of cultivated land; or country of which the climate is characterised by a period of heat and dryness during which vegetation disappears almost entirely. The Rhine, Po, Oxus, and Hoang-Ho are subject to these conditions, and their waters are very

turbid. The Hoang-Ho is the most marked case, and its mouth has changed many times, owing to the quantity of detritus, and has been displaced from 31° to 39° N. latitude. The river traverses the loess of north-west China, a formation easily cut into ravines. These are so great and ramified that war-operations proved to be more difficult there than in a mountainous country; even the roads are deep ravines. Originally the country was doubtless a plain, under a rich vegetation. When the land began to be cultivated the soil was bared, and ravine formation began and has continued for four thousand years. Now the Hoang-Ho is the richest in mud of all great rivers.

The effect of the drainage of land is to increase the irregularity of rivers. In a case in Ireland, referred to by Mr Mallet, the flood-water of a river meandering over meadowland encumbered with vegetation took a fortnight or three weeks to travel twenty miles. After main channels were opened the flood-waters came down in two days. Again, according to Mr J. B. Denton, experiments at Hinxworth have shown that a clay soil, before draining, lost 13 inches per annum more rainfall by evaporation than after it was drained. This 13 inches of rainfall went to increase the volume of the rivers. All experience has shown that where land has been drained the rivers have become more irregular, with the exception of chalk-land, because chalk is very porous, and under-draining enables the chalk to absorb the rainfall more readily than before, and so prevents floods. As the denuding action of a stream is practically confined to seasons of flood, anything that increases the rapidity of flow assists the river to erode and to carry away the soil, and hence improvements in drainage increase denudation. Even in England indications of ravine formation, due to cultivation of the land, have been observed.

Professor Wollny experimented on three pieces of

land sloping at 10°, 20°, and 30° respectively, and maintained them for a year without vegetation. He found that the weight of detritus, in grams, removed by rains and melting snow, per square metre of surface, was as follows:

Grassed soil			Bare soil		
10°	20°	30°	10°	20°	30°
13.9	41.6	50.8	834.8	2368.4	3101.1

These experiments show that denudation was about sixty times as rapid on bare soil as on a grassy surface. Wollny suggests that trees would be still more effective than grass as a protection.

The destruction of forests has also led to the formation of moving sand-dunes. In Russia, during the last thirty or forty years, many moving sands have originated which threaten to destroy the neighbouring cultivated lands. During storms in dry seasons the soil and subsoil is lifted by the wind and deposited against hedges, hollows in the ground, or in fact wherever the wind is more feeble. In some parts of Russia deposits form on the railways up to nearly 30 metres in height.

On a small scale the same effect is observable in England; for example, in the Sherwood Forest district of Nottinghamshire, which has a sandy soil (Bunter), sand-drifts are often heaped up against the hedges, and near Edwinstowe these drifts have been noticed fully 8 feet in height. The hedges offer considerable resistance to the free movement of the dunes, but a good deal of sand must nevertheless be blown away, for near Annesley, where the Bunter sand is brought against limestone by a fault, the drifted sand lies 3 feet deep over the limestone for several hundred yards from the fault.

The countries east of the Adriatic—Idria, Dalmatia, Herzegovina, Montenegro, parts of Carniola

and Croatia—have become by negligence deserts. The rainfall is very abundant, and part of Dalmatia and Herzegovina, at least, were once covered with forests, which were cut down to build the Venetian navies. Cattle destroyed the young shoots, and humus, deprived of the protection of the trees, was washed away by rain, and the limestone below laid bare. Rain falling on this runs into the fissures, and, the rock being soluble, funnels are formed by which the rains discharge themselves very quickly into subterranean streams, leaving the country a desert. The Carso, so prominent in the accounts of fighting on the Italian front during the recent war, is a part of the limestone desert produced by Man's neglect. Steps are now being taken to repair the mischief done, and the Austrians have planted forests, as have also the French in the Alps and Cevennes.

Marsh has pointed out the striking difference between the condition of the countries of the Mediterranean and the Near East at the time of the Roman Empire and now. Then, these countries were fertile and prosperous, now more than half the area is either a desert or is greatly reduced in both population and productiveness. Northern Africa, Arabia, Syria, Armenia, Asia Minor, Mesopotamia, Persia, and even parts of Italy and Spain, once rich agricultural lands, are now unproductive. The explanation given is, firstly, ignorance of Nature's laws, and secondly, bad government and civil wars.

Snow and Avalanches.—It has long been known that, in spring-time, snow melts more rapidly in places free from vegetation; and rapid melting of the snow means floods. Ismailsky has pointed out that, when travelling through the steppes in spring-time, the roads opposite fields were already dusty, whereas the parts traversing virgin steppe were impassable on account of the mud. Again, in bare land the snow is exposed to tempests which blow it away freely and pile it up anew

in dangerous accumulations. Trees are also the best protection against avalanches, which in addition to the destruction they cause to life and property, tear away the soil and leave the bare rock.

Effect of Destruction of Forests on Temperature.—One effect of a forest is to lower the temperature of the district. This effect is mainly due to the evaporation of water by the leaves of the trees, which absorb heat in the process. The roots of trees extend deeply into the subsoil, where there is always water, for during the rainy season of the year the rain penetrates to the subsoil and is there held as in a sponge. Grasses, however, which are the chief crops grown by Man, are shallow-rooted (except perhaps wheat) and suffer from the effects of drought, for they are unable to reach the water reservoir below them. The constant evaporation carried on by trees causes a lower temperature to exist in woodland than in cultivated lands. As an example, the temperature of the plain of the Upper Amazon, east of the Andes, which is densely wooded, has a temperature lower than that of Para and Pernambuco on the coast, although the rule is that the coast of a continent is much cooler than the interior.

The formation of ravines in cleared areas increases the temperature locally in two ways, namely, by facilitating the drainage and thereby drying the soil; and, secondly, by allowing the air, chilled by contact with the soil at night and in winter, to flow away. A plateau dissected by ravines is therefore warmer than before dissection.

Effect of Forests on Rainfall and Drainage.—Forests not only offer protection from winds but this action incidentally increases the rainfall, for W. Koeppen has shown that a gentle wind allows the air in motion time to be thoroughly chilled and so causes the moisture contained to fall as rain. In this manner, as well as by keeping the air humid, forests increase

the rainfall. These actions are modified by Man cutting down or planting trees. Every change in the surface of the land, as well as drainage, irrigation, and the working of arable land, all modify the climate. One of the most important factors is the cultivation of rice. This cereal, which forms the staple food of hundreds of millions of human beings, is grown in artificial marshes. Natural marshes are usually covered with high vegetation which protects the water-surface from the sun's rays; but the shallow water on the rice-fields, which cover an immense area in India, Indo-China, China, Java and Japan, is strongly heated by the sun's rays. The temperature of the water in rice-fields has not yet been investigated, but it is doubtless much higher than that of rivers, lakes, or seas, where, owing to the depth of water and its movements, the heat is not concentrated in a thin surface-layer of quiet muddy water. Many rice-fields were dry districts before Man took them in hand; now they are kept humid by the great evaporation. Woeikof thinks that the prolongation of the monsoons towards autumn is in part due to evaporation from the rice-fields.

Near Bordeaux is the Landes of Gascony—before 1850 an uninhabited desert of nearly two million acres. The surface is a nearly horizontal plane about 330 feet above sea-level. The soil, which is from 12 to 20 inches in thickness, is agglomerated by a kind of organic cement called "alios." This is underlain by compact white sand full of water. In summer there is no trace of water on the surface: in winter heavy rains fall for six months and lie stagnant until they evaporate during the summer. The inclination of the surface averages 1 in 1,000, but in places is not more than 1 in 2,000, and the only irregularities of the surface are never more than 12 to 16 inches above the normal slope. At first 50,000 acres were reclaimed by shallow drains, and firs and oaks were planted; later 720,000 acres were drained, and by 1879 about $1\frac{1}{2}$ million

acres of the desert had been reclaimed and turned into forest.

Investigations by Monsieur Fautrat, in 1874, in the forest of Halotte, showed that the effective rainfall over the forest was to that over open country in the ratio of 100 to 92·5, and taking into account the protection from evaporation afforded by trees, the effective rainfall might be twice as much in the forest as in the open country. Hence forests are largely instrumental in supplying water-courses.

Effect of Drainage on Temperature.—According to J. Bailey Denton, experiments by Mr Buchan have shown that the temperature of the soil has been raised in some cases 3°, often 2°, and still more frequently $1\frac{1}{2}$° by draining; hence the effect, in many cases, is as if the land had been transported from 100 to 150 miles nearer the equator. Dr W. Rankine found that at 10 inches below the surface the temperature was raised 0·8° by under drainage, while Mr Denton found that at 18 inches below the surface the temperature of drained land was 2° higher than that of undrained land. In some cases much greater results than these have been found. Thus, Josiah Parkes discovered that the temperature of a drained bog, at 31 inches from the surface, was 10° higher than in the undrained bog, while Professor Schubler's experiments proved that rain falling on drained land supplied heat and raised the temperature 6° at a depth of 4 feet. The increase of temperature is probably due in part to chemical reactions, such as oxidation of organic matters and ferrous compounds, in the soil.

Scenery.—It seems desirable to refer briefly to the changes in the appearance of the earth brought about by Man, although from a geological aspect scenery is of minor importance.

Britain, in pre-Roman times, was an inhospitable land, almost covered by woods, moors, and fens. Although it had been inhabited for thousands of years,

primitive Man probably produced little or no effect on the aspect of the country. The Romans no doubt altered the primeval appearance to a considerable extent along the lines of their roads; nevertheless, from the account of England as it was in the sixth century, at the time of the Anglo-Saxon invasion, given by J. R. Green in "The Making of England," the country was then still in a very unsettled condition. After the Romans had departed Britain relapsed, to a considerable extent, into its primitive condition. The roads made by the Romans decayed and others were mere tracks, the maximum deterioration being reached about the beginning of the sixteenth century. Some account has already been given (p. 97) of the condition of the roads in the Middle Ages.

Apart from a few mountainous regions such as parts of the Scottish Highlands, which may retain their original aspect to a considerable extent, the scenery of Britain has been completely altered. The general enclosure of land must have transformed the country-side, while the growth of the towns and of industries during the last hundred years, with the necessary accessories of paved roads, railways, canals, reservoirs, etc., must have caused Britain to present an appearance that would be utterly strange to a man of the Middle Ages could he revisit the country.

The characteristic scenery of a coal and iron district may be seen in the region known as the Black Country, lying between Wolverhampton and Birmingham. If, for example, one takes a walk from Wolverhampton to Wednesfield one crosses a wild-looking and barren waste, divided by a few fences or dilapidated hedges, but broken up by railways, canals, and an occasional road. Grimy clumps of cottages occur at intervals, and one has distant views of tall chimneys, while over all is a smoky sky, which, however, gives rise to fine sunsets. Remains of the original surface are seen here and there between accumulations of colliery-waste

and slag. The mounds are of every size and shape, though as a rule they are flat-topped, rising about 15 to 25 feet above the natural surface-level, and covering from one to many acres. In some parts the mounds are entirely composed of black shale broken into small fragments, in others the material is largely slag from the furnaces, sometimes in craggy masses several yards across. Special industries have locally added waste of unusual kinds, as, e.g., chemical waste. Bits of brick and rubbish of every kind are seen scattered over the ground. Here and there ponds covered by green algæ fill hollows sometimes 40 feet below the surrounding level.

Perhaps the closest natural resemblance to this black desert will be found in districts that have suffered from an outpouring of lava and scoriæ before there has been time for the rocks to decay and be covered by vegetation. The scenery suggests a volcanic region in other ways. The slag is not unlike the scoriæ of lava; also the slope of the mounds resembles that of a volcanic cone built out of ashes. On these mounds rain-gullies form. At an early date rivers dig out a drainage-system which is, in miniature, precisely similar to a natural system. One may see gorges and alluvial flats and all the phenomena of river erosion on a pigmy scale. Eventually the shale will weather into clay, while some of the slag contains phosphates which are liberated on decomposition and help to enrich the soil. It is only a question of time before the mounds will become completely covered by a green mantle. This process can be seen in the Black Country, for the mounds bear thin patches of such hardy weeds as thistles and coltsfoot, the forerunners of a complete covering of vegetation. In the Coalbrookdale coal-field, where many of the tip-heaps are a century old, the process has gone further and the mounds are to a considerable extent covered by grass. Man, however, is helping Nature, and a society has been formed to

reclaim the Black Country. East Park, Wolverhampton, is an illustration of what can be done in this direction, while not far away a bowling-green marks a clear victory over the wilderness. Part of the area, too, has been levelled and built over, and there is then nothing to show that the ground is not the natural surface. Owing to the increasing demand for tarred macadam the old heaps of slag are being utilised, and we may look forward to a time when the slag-mounds will have disappeared. In short, the striking scenery of the Black Country may be expected to become gradually more and more normal.

Other coal-fields resemble the Black Country more or less closely. In some cases, as in South Wales, the natural features are on too large a scale to be masked by waste, and the original appearance had been little modified.

The slate-quarries and mines of North Wales have also had a marked effect on the scenery. At Blaenau Ffestiniog, and elsewhere, the mountains are covered with talus-fans, made of fragments of slate from the mines, to a height of over 1,000 feet. So enormous is the quantity of slate excavated that Professor Davis has estimated the human denudation in Snowdonia as equal in amount to all the natural denudation that has been effected in the district since the Glacial Epoch.

Few parts of Britain have escaped radical changes in aspect. Even a barren moor like Dartmoor has been transformed; for at one time it was covered by trees. These were cut down to smelt the tin-ore, and owing to lack of shelter from the winds the moor has remained bare ever since. Clement Reid, in the "Geology of Dartmoor Forest," has given a striking account of the only patch of primeval woodland that has survived the smelter.

Dartmoor serves to illustrate another remarkable change in scenery. The area of the moorland is now about half of what it was when it was a Chase (it was

never a Forest in the legal sense) reserved for hunting. Gradually it has been enclosed, piece by piece, drained, and the loose stones picked off and built into walls. The contrast between the open moor covered with loose stones and the smooth pasture inside the walls is very striking, and enables us to realise to some extent the great change brought about by Man in the aspect of Britain. We have referred on p. 119 to the extent to which loose stones have been built into walls or broken up for road-metal. In earlier days many were tumbled into ruts in the roads without being broken.

Landslips are not uncommon results of human activities. A striking instance may be seen at Hickleton, north of Conisbrough, where a part of the Magnesian Limestone escarpment has been undermined for coal and has slipped forward, forming a faulted mass.

In the chapter on Subsidence instances have been given where swamps have been formed in consequence of mining operations. At Northwich there are scenes reminiscent of the Western Front. Swamps are well marked round Wigan, but not many miles away we may see the reclamation of a bog, for the famous Chat Moss, which offered such a tremendous problem to George Stevenson, when making his first railway, has mostly been reclaimed by filling it up with the refuse of Manchester. The former bog is now solid land fit for agriculture.

The rubbish from towns is to an increasing extent being burnt in destructors, and the clinker made into paving-blocks, or concrete. In these cases the effect on the scenery is negligible. In other cases, however, the waste is dumped in some convenient quarry or valley, and there it forms terraces. Almost every town offers illustrations of this, even where a destructor is now installed. Also there is, of course, trade refuse not suitable for a destructor. As the waste is carted,

or transported on rails, and then dumped, a flat is formed, with a steep edge whose inclination is the angle of repose of the material. The flat grows in area as the point at top of the original cone extends into a surface, but the marginal slope retains its inclination. When the waste is tipped into a deep valley a second or a third flat may be formed upon the first. In valleys the flats have somewhat the appearance of river-terraces, and the imitation becomes more marked when plants have covered the rubbish.

Usually roads along river-valleys are raised more or less above the river level, to prevent flooding, and the terraces of rubbish usually grow out from the road as the material is tipped from carts until a flat that may be many acres in extent is formed at the road level, and in time this is likely to be built on.

The view of Pumpherston tip-heap, 11 miles W.S.W. of Edinburgh (Geological Survey Photograph), offers a splendid illustration of a man-made hill. Four terraces can be seen in the figure. Part of the lowest, seen behind the telegraph wires, has evidently been built up along parallel lines so that the cones first formed became greatly elongated pyramids which have not, as yet, been fully compacted together. Behind is a lofty second terrace deposited on the lowest terrace. The third terrace has almost completely covered the second terrace, but a little remains, and on the right hand side of the hill a fourth terrace is being formed. The scale is given by the wagon and the hut on the top of the hill as well as by the buildings and telegraph poles in the middle distance. These tips of burnt oil-shale are perhaps the most lofty waste heaps in this country (Plate facing p. 207).

The photograph of Messrs Bolckow, Vaughan and Co.'s highest tip-heap, between Middlesbrough and Redcar, is kindly supplied by the firm. This heap is also built up in terraces, but in this case the waste material is semi-molten slag. The side facing the

Tees estuary has all the appearance of a natural cliff in lava (Plate facing p. 203).

Quarries vary greatly in shape, but in a majority of cases they are cut out of elevated ground and have a tendency towards a horseshoe shape, with a flat floor. Even where the rock is dug out below the level of the approach road the hollow is often filled up, at a later date, by waste material, whether from the quarry or from an adjacent town. The resemblance of a horseshoe shaped quarry in a hillside to a coombe, corrie, or cwm, caused by glacial action, is striking; although the quarry is usually on a much smaller scale. There is the same precipitous wall diminishing to nothing in front in both cases. When the quarry is situated some distance up a hill-slope which is continued below the floor, we get a further resemblance (Plate facing p. 327).

When the quarry, or mine-adit, is in a steep hillside the waste material is usually thrown down at the entrance and forms a talus-fan similar in appearance to a natural fan formed at the mouth of a torrential stream. In time a more or less extensive terrace is built out opposite the quarry. Some quarries are dug out of flattish ground to a considerable depth, and in that case the result is a cavity with approximately vertical walls. The great Storeton Quarry in the Wirral Peninsula is of this type (Frontispiece). Usually the cost of obtaining stone at increasingly great depths and the difficulty of keeping out water, or a failure in the demand for the stone, cause the quarry to be abandoned. After remaining derelict for a period, probably partially filled with water, it is likely to be filled up with refuse and to disappear.

Embankments and cuttings are striking features in a landscape. The former have counterparts in Nature in eskers, moraines, and kames, left by the Great Ice Age; the latter in certain dry valleys cut by water escaping from lakes dammed by glaciers. The next

plate is intended to show the similarity. A railway has been constructed through a channel cut by water escaping from a temporary lake held up by ice. At the left side of the gap a small notch has been cut by Man, but the remainder of the gap is natural. The embankment in the foreground is artificial. The channel serves the purpose, and has the appearance of a railway-cutting. The plate facing p. 323 (of a railway-cutting near Dover) shows how closely an "in-and-out" channel, cut by glacial waters, is imitated by Man.

Lakes are characteristic of glaciated countries, and with few exceptions are confined to them. Man, however, is also a lake-maker; water is ponded up in valleys or on flats for various purposes, and the larger of these are quite comparable in size with natural lakes. Thus Vyrnwy, an artificial Welsh lake, is larger than any natural lake in Wales. In various ways the influence of Man on Scenery is more like that of Ice than of any other agent.

It will be noticed that the general effect of Man is to level down hills and fill up hollows, thereby producing a succession of terraces. A type of terrace that deserves mention here, because although not common it is one of the most striking relics of early Man, is the cultivation terrace. These lynchets, as they are called, are benches cut in a hillside too steep for cultivation. The step-like terraces enable soil to remain on the hillside instead of being washed away by rain. They are very well seen from the London and North-Western Railway on the west side of the line after passing through the Tring cutting. They are cut into chalk on the southern face of Southend Hill.

There is a tendency for terraces to be destroyed at a later date, and the final effect of human activities would probably be, if there were no counteracting agents, to produce a flat surface falling uniformly and very gently towards the sea, a peneplain, in fact, such

NATURAL CHANNEL CUT BY GLACIAL WATERS AT SLOCHD BEAG, INVERNESS-SHIRE, AND UTILISED AS A RAILWAY CUTTING.

(Geological survey photograph.)

RAILWAY CUTTING, NEAR DOVER, RESEMBLING "IN-AND-OUT" CHANNEL CUT BY GLACIAL WATERS.
(Geological survey photograph.)

as atmospheric agents tend to produce. Of course it is highly improbable that natural forces will be quiescent sufficiently long for this result to be reached, but it is interesting to note that, using different methods, Man arrives at the same end as Nature.

The great changes of scenery brought about by the introduction of new plants are biological and not geological effects of human interference, and therefore need not be discussed here.

CHAPTER X

CONCLUSIONS

In this chapter I propose to gather up the threads and see what general inferences can be drawn from the data set out in the preceding pages.

In the early days of the science, geologists were divided into two schools, those who believed that Nature worked mainly by occasional catastrophies alternating with periods of inactivity, and those who thought that natural agents worked smoothly and ceaselessly throughout the ages. The latter school, founded by Hutton, was supported by Sir Charles Lyell, whose great work, " The Principles of Geology," was intended to prove that the forces of Nature had always acted at approximately the same rate as at present, and were fully competent to produce all the results known to geologists, given sufficient time. Under Lyell's powerful influence the Uniformitarians prevailed over the Catastrophists, and until recently seemed to be completely victorious. However, there are indications that the doctrine of Uniformity has been carried too far.

We are so accustomed to steadiness in Nature that we assume that she always acts with deliberation and never varies her methods. For example, we assume that a valley has been dug out by the river now flowing down it, although there is no deepening visibly in progress. We draw a big draft on time, and put back the age of the valley by a sufficient number of thousands or millions of years to give the river an

opportunity of doing the work. We are, however, beginning to realise that under climatic conditions different from the present ones, and such as occurred in and after the Great Ice Age, the valley could be scooped out in a comparatively short time, and that at present the rate of denudation has slowed down. It becomes apparent, also, that such deepening as is even now being effected is the result of exceptional storms producing torrents that sweep away more material in a day than the river normally moves in half a century. Such instances indicate that Man has exaggerated the steadiness of Nature, and that a succession of small catastrophies alternating with steady periods is the truer idea. Spread over a geological period, minor catastrophies are not apparent, just as to an observer in an aeroplane minor irregularities in the earth's surface disappear and a false idea of flatness is obtained. It may be correct that the formation of 10,000 feet of rock belonging to one geological period represents about the same lapse of time as was required for the formation of the same thickness of rock during another geological period, and yet a closer investigation might show great variations in the speed of accumulation of different parts of the rock masses.

From this viewpoint the work of Man resembles that of natural agents that are known to have acted with exceptional power at intervals in the earth's history, e.g., the action of ice is purely natural and constantly with us, and yet the intervals between the three or four Ice Ages that have occurred are measured in millions of years. To the men who lived during the last Ice Age the conditions must have seemed the natural state of things, although to us they are difficult to conceive. The differences between the purely natural conditions of denudation and accumulation, when tropical animals and plants lived in what is now England, and the time that followed, when the country was in the condition of Greenland, were at

least as great as any changed conditions wrought by Man. Moreover, it has been shown above that the actions of Man have been, so far, limited to a much briefer period than that of an Ice Age, and although we cannot say how long human interference will last, it is evident that Man's geological work varies frequently, and that he undoes to-day much that was done yesterday, thereby considerably diminishing his nett activities.

A marked characteristic, then, of Man's action on Nature is its intermittency: while his geological activities grow in power they are for ever changing their direction. For instance, the rate at which road pavements are being worn out is such that, if continued through a geological period, the denudation would be enormous; but in point of fact the rate has increased from a very small figure, before the nineteenth century, to its present amount, and already there are indications that the rapid introduction of organic materials for pavements has checked the advance, and may soon diminish the rate at which the inorganic materials are being destroyed. Here, therefore, the period at which the rate of denudation is high is limited, and may prove to be less than a century. To take another example; practically all the British canals, with the exception of the Manchester Ship Canal, were made in the period from 1761 to 1830, and nearly all of them by 1800. In 1830 the Liverpool and Manchester Railway was opened, canal-making came to a close, and, instead, railways were made in great numbers until 1845, when it was discovered that they were becoming too numerous, and a slump set in. From that time railway construction fell off greatly, although a number of miles of new railway are still built annually, and the Great Central, probably the last main line to be constructed, was completed so recently as 1900. The excavation of earth and rock during the making of the canals, excluding the Manchester Ship Canal, was

CHALK PIT, NEAR MAIDENHEAD, RESEMBLING A GLACIALLY FORMED CORRIE.
(By permission of Ll. Treacher, Esq.)

about 200 million cubic yards (see p. 83), and, up to date, railway making has been responsible for the excavation of about 3,000 million cubic yards. The period of canal construction was only sixty-nine years, and nearly all were built within thirty-nine years; while the main activity of railway building lasted only fifteen years, and the full period, to date, is only ninety years. Speaking geologically, these times are negligible, and can be more readily compared with a cataclysm than with the activity of the atmosphere, the sea, or other geological agent acting through the ages. The activity of a volcano, such as Vesuvius, which slumbers for centuries, and then is in eruption with short intervals of only a few years, is more readily comparable. The main eruption, followed often by spasmodic returns of activity, is analogous to the energetic construction of canals during thirty-nine years, followed by thirty years of waning activity, reviving after fifty-seven years of total extinction with the making of the Manchester Ship Canal.

A similar unsteadiness is apparent in the effects of Man's activities. Instead of producing a flat or smooth curving surface he makes the ground very uneven, producing terraces, holes, and mounds, in a most sporadic manner. In its geological effects human work resembles that of a glacier more than any other natural agent. The morainic material called "kettle drift" bears some resemblance to the waste heaps left by Man; eskers and kames produced by ice often closely resemble embankments in outward aspect, and may dam up water into lakes in a similar manner. Again, as has been pointed out already, the denudation of pavements has a nearer resemblance to the graving of ice than to any other natural agent. Quarries bear frequently a close resemblance to coombes and corries, made by glaciers; railway- and canal-cuttings resemble certain glacially cut channels (p. 321); glaciers and Man alike frequently abrade unweathered rocks.

Finally, the period of the Great Ice Age was, geologically speaking, a short one, and although we now know that there have been several Ice Ages, yet in their occasional character they resemble the work of Man.

A very important point of difference between natural and human denudation is the extent to which it is carried. If we examine a conglomerate such as one of those in the Bunter formation, we find that it often contains exceedingly hard pebbles, as, for example, the well-known quartzite pebbles of the Bunter. The original formations from which the pebbles are derived are often Pre-Cambrian or Older Palæozoic, i.e., the oldest rocks known. An individual pebble is often utilised over and over again in rock-making. A quartzite pebble in the Glacial Drift is often derived from the destruction of a Bunter conglomerate, which, in turn, may have derived it from a Devonian conglomerate destroyed at the time of the formation of the Bunter rocks. The pebble may contain an Ordovician fossil, showing that in Devonian times it was already a hard rock. Lately, Professor Garwood has found quartzite-pebbles, exactly like typical Bunter pebbles, in Pre-Cambrian conglomerate, so that some of the pebbles must have existed in exactly their present form at the most remote period of geological history. No doubt each time the rock in which the fragment lay has been denuded the pebble was slightly reduced in size. How small a loss pebbles normally suffer in one of their peregrinations is often well seen in pebbles normally found in the Glacial Drift and derived from the Bunter. These sometimes get broken along a joint-plane under the pressure of the ice, and the slight rounding of the broken edge, which represents the attrition since the fracture, is in marked contrast to the perfect smoothness of the rest of the pebble. In fact, a hard quartzite-pebble is almost everlasting; at least its life

may be hundreds of millions of years. When, however, Man uses such pebbles for road-making the stones lose their identity. The road will presently be taken up and re-made, but the pebbles, now worn flat on one side, can be used again and again, and, lying in a new position, will have another flat surface worn on them. The pebble is finally reduced to a small size, the greater part of it having been triturated into the finest dust. The hard banket of Johannesburg, a conglomerate of quartz-pebbles, is ground to a fine powder, pebbles and matrix alike, in order to free the particles of gold (p. 124).

In Nature trituration occurs by the action of waves, rivers, ice, and wind; and also in volcanic eruptions. It is usually accompanied by chemical changes, so that soils, the normal result of atmospheric denuding agents, are not simply powdered rocks, but differ considerably in composition from the parent mass. For example, an igneous rock exposed to the action of the air has its felspars decomposed with the formation of "clay"; the potash and soda being to a considerable extent dissolved out, the ferrous compounds are decomposed by the oxidation and hydration of the iron, and carbonates replace silicates in part. By these changes the rock becomes incoherent, and passes, by stages, through rubble into soil, which is destined to be washed away into the sea, where it is sorted into sand and clay, and deposited. When the same igneous rock is quarried by Man for road-metal he rejects the outer partially decayed rock and uses the hard, unaltered inner parts, which he proceeds to reduce to powder by mechanical and not chemical means. The dust, therefore, has approximately the composition of the original rocky mass and differs widely from the clay produced by natural agents.

Another important difference between natural and human denudation is that natural denudation removes by preference the softer and more easily destroyed

rocks, and so the less resistant form valleys while the more resistant make ridges and plateaux. If the difference in destructibility is great, the shape of the ground is rugged in proportion, and so we find wild crags, composed of massive igneous rocks, set amongst softer materials. Man, however, selects for excavation such rocks as will be of economic value, or which are obstacles in the way of his projects. Thus rocks will, regardless of their nature, be removed to make room for railways or roads, or to reach stable foundations. In other cases a hard igneous mass will be quarried for road-metal or building-stone and the surrounding soft rocks left untouched, e.g., in Charnwood Forest. In these cases Man makes a hole where Nature intended a hill. At other times a loose sand or a brick-earth may be selected for quarrying. We may notice that Man does not ignore the resisting powers of rock, for if it is reasonably easy to avoid cutting through a hard rock to make a railway he will do so; at other times, as in the case of road-metal, he deliberately selects hard rocks for excavation.

We found that the total excavation by Man in Great Britain was of the order of 40,000 million cubic yards of rock, which if taken uniformly from the surface of the British Isles would be equivalent to the removal of a layer 3·83 inches in thickness. Omitting Ireland, from which a small but unknown amount additional to the 40,000 million cubic yards has been excavated, the layer would be 5·24 inches. The excavation, of course, is not uniformly spread, and the bulk excavated in Scotland north of the Firths of Forth and Clyde would be inappreciable compared with the volume excavated south of that line. We may therefore imagine the total excavation to be concentrated in England, Wales, and the thirteen most southerly counties of Scotland; that is approximately the whole of Great Britain south of the Clyde and Forth; or on an area of 65,226 square miles. On this

area the material removed is equivalent to a layer of rock 7·12 inches in thickness.

Next we may divide the total excavation into that below ground (mines) and that above ground. Apart from tunnels, wells, and borings, all the forms of excavation in the table on p. 86 may be added to the amount from quarries to give the total of surface excavation. The quantity of material removed in tunnels, wells, and borings, can only be guessed at. That it is very considerable is indicated by the figures on p. 167 which show that within London alone the Tube Railways and Inner Circle were responsible for the excavation of 11,262,000 cubic yards. As it is desirable where figures do not permit of exactness to deal with round numbers we shall assume that the excavation from tunnels (whether railway, canal, water-supply, or for road traffic), wells, and borings, altogether amount to 308 million cubic yards; this being the amount required to make the 19,692 millions obtained from mines into the round sum of 20,000 million cubic yards. Hence the total excavation from below the ground is about equal to that from open excavations at the surface.

Here we remark that Mr G. W. Lamplugh (in " On the Taming of Streams ") came to the conclusion that Man's geological activities worked, on the whole, with gravitation. It appears, however, that this is not the case in Great Britain, for the total material brought up from mines, against gravitation, is approximately equal in bulk to that dug out at the surface, and which, on the whole, is moved to lower levels. These figures refer to Man's total work since the earliest times, but the vast bulk of the work was done by modern Man, and during the nineteen years ending 1913 the rock mined was about six times as much as that quarried.

Although the total amount of rock excavated is equal to a layer 7·12 inches in thickness, this is not the

amount by which the country south of the Forth and Clyde has been lowered, for we must remember that the rock mined produces a subsidence equal to only a fraction of itself. We have given the fraction the average value of 30% (p. 156) and therefore the lowering of the surface will be, not 7·12 inches in all, but 3·56 inches due to surface excavation, and 30% of 3·56 inches from subsidence caused by mining, or a total of 5·628 inches in about two thousand years, which is about ·2814 inches per century. The remaining volume excavated, namely, 14 million cubic yards (i.e., 70% of 20 millions), remains as spaces in the earth's crust. To this must be added a large part of the 43 million cubic yards of minute spaces left by the removal of rock in solution from mines and deep wells (p. 286).

Let us now compare these figures with the rate of natural erosion. Sir Archibald Geikie, in his Text Book of Geology, states that the rivers mentioned below remove rock from the general surfaces of their basins in the following ratios: The Mississippi removes one foot in 6,000 years; the Danube in 6,846 years; the Po in 729 years. At the Mississippi's rate of denudation North America, assuming the average height to be 748 feet, would be reduced to sea-level in about $4\frac{1}{2}$ million years. On the other hand, Europe, with a mean height of 671 feet, would be worn down to sea-level in less than half a million years, if denuded at the rate the Po denudes its basin. Geikie estimated that for the British Isles the rate of planation is about one foot in 8,800 years. These figures do not include the loss in solution, estimated by T. Mellard Reade at approximately one-third that removed in the solid form; but it is pointed out that the loss by solution does not necessarily lower the level to the same extent as that planed off the surface, because much of the dissolved rock is removed from subterranean sources.

The rate of planation for the British Isles given by

Geikie, namely, a foot in 8,800 years, is equivalent to 2·72 inches in 2,000 years, or less than half that due to Man during the same period. We have found, however, that by far the greater part of Man's work was done during the last century, and it follows that at the present time, in a densely peopled country like England, Man is many times more powerful, as an agent of denudation, than all the atmospheric denuding forces combined.

It may be thought that in estimating the rate of human denudation we have forgotten to allow for human accumulation. In Chapter VI we have shown that Man is a rock-maker as well as a rock-destroyer. Nevertheless, accumulation is small compared with denudation. Consider, for example, that of the 12,667 million cubic yards of coal excavated (p. 24) only the ash remains, the rest has disappeared into the atmosphere. The metal iron, representing about 35% by weight of the iron-stone won, rusts and disappears, and the other metals also vanish in various ways. Even gold, which never corrodes and owing to its high value is carefully preserved, disappears. Coins lose weight by attrition and need to be periodically withdrawn from circulation for re-melting. Gold jewellery also suffers from attrition, as is very evident in a wedding-ring. A considerable quantity of the metal is used as gold leaf; in gilding; in toning photographs; and finally, some is lost at sea. If even gold has a temporary existence, that of the commoner and corrodable metals must be even more transitory.

Much quarried material is rubbed away on roads (p. 112), and by other means reduced to dust, which readily finds its way into rivers, and so into the sea.

In the case of bricks and pottery a soft clay is burnt into a hard rock, but we have seen (p. 226) that after sixty years this material passes in a fragmentary condition into " made ground," where it is mixed with masonry, concrete, slag, and every other product of

human activity that has survived decay. " Made ground " is itself an incoherent and superficial deposit, analogous in texture and position to a river deposit or glacial drift. We know that river and drift deposits are almost unknown in past geological periods, owing to the feeble resistance they offer to denudation, although in an exceptional case, as when a sheet of lava has flowed over a terrace, it may be preserved. We conclude therefore that, geologically speaking, Man acts as a denuding agent, and that his accumulations are temporary and not to be offset against the material excavated, when considering the rate of human denudation.

The rate of denudation by the Mississippi is usually taken as the standard for rivers, because the area drained by it is so large that it includes all kinds of land and a large variety of climates. It is in marked contrast to the rate of denudation of the Po, which flows through the highly cultivated plains of Lombardy. At the same time the basins of the two rivers are so different in size that it is not possible to compare them directly, for the Po basin is so much the smaller that it does not contain the variety of lands and climates that the Mississippi basin does. However, the Hoang-Ho, a very considerable river, flowing through highly cultivated country, has also a much higher rate of denudation than has the Mississippi, and it is very probable that the differences between the rivers given by Geikie (p. 332) are due to a considerable extent to human activities. Even the Mississippi and its tributaries pass through much cultivated land and the river has been tamed to a considerable extent (p. 271). We do not seem to possess reliable data of the rate of denudation by large rivers still in the natural condition. The Congo and Amazon basins are scarcely touched by Man, but both rivers flow through vast tropical forests. They might, however, be compared with such rivers as the Lena and Mackenzie, which flow through

Arctic lands, and the average of the two types might give a better average figure for the untamed river than does the Mississippi. A recent investigation by Sir A. Strahan and others, for the Royal Geographical Society, gave the rate of denudation by the River Exe measured at a point just above Exeter, as 1 foot in 7,767 years. It is pointed out that all English rivers are well on towards maturity and none are rolling material along their beds directly towards the sea.

It is very important to geologists to find the average rate of denudation of the land under natural, as distinct from artificial, conditions, for geological chronology is largely based on these figures. The differences between the rate of the Mississippi, Hoang-Ho, and Po are startling, and it seems highly probable that, until the influence of Man on denudation has been more completely studied and allowance made for it, calculations of geological time may be far from the truth, the errors tending probably to give a period much too small.

Sir A. Geikie has estimated that the sea wears back the coast at the rate of about a mile in 52,800 years. In the absence of changes in the relative levels of sea and land, marine erosion rapidly falls off, in consequence of the protection offered to the land by the submarine plane formed by the sea in front of the coast.

The effect of Man on the coast appears to be, on the whole, protective; judging from the fact that during the thirty-five years ending 1911 the British Isles have increased in area by 41,362 acres (p. 245). It is probable that it is only in recent times that the land area has been increased; for reclamation and protective works are almost all modern, while, until a generation or two ago, destruction was caused by the removal of shingle. At present it is not possible to say if the recent gains are greater than the losses that took place during many preceding centuries.

We found that Man's works on the coast have all been dependent on the accident that we live in a period of earth quiesence. So recently as 4,000 years ago there was a marked subsidence, and Reid has pointed out (p. 239) that a rise or fall of the land amounting to only a few feet would have disastrous effects on all our coastal works as well as seriously disturb the inland drainage. This is a good indication of the impermanence of human efforts.

The amount of geological change brought about by Man will depend on two factors, firstly the density of population, and secondly the degree of engineering energy shown. Both factors have been increasing since prehistoric times.

The population of England at the time of Domesday Book was about two millions; it increased slowly and reached perhaps four millions in 1348, when the Black Death destroyed from one-third to one-half the people, and a succession of wars and pestilences kept the population from increasing again until Tudor times. In the following table the first three lines are from Mulhall's Dictionary of Statistics; the next two from the Statistical Journal, quoted by W. Cunningham in " The Growth of English Industry and Commerce in Modern Times "; and the rest from the Census Returns:

Year	Population of England and Wales	Persons per sq. mile
1066	2,150,000	
1381	2,360,000	
1528	4,356,000	
1700	5,475,000	
1750	6,467,000	
1801	8,892,536	152
1831	13,896,797	238
1861	20,066,224	344
1891	29,002,525	497
1911	36,075,269	618
1921	37,885,242	649

The table shows that the population of England and Wales was small at the time of the Norman conquest and increased but slowly for several centuries. About 1830 the rate of increase became accelerated.

As regards the second factor, the increase in engineering energy, the same thing happened in a more marked degree.

The increase in engineering works is well brought out by Louis D'A. Jackson in " Four Centuries of European Progress." He says that in the tenth century, fourteen towns were rebuilt in England by the monks, and of the two most noteworthy events of the century one was the introduction of sewage irrigation in Northumbria by the Anglo-Saxons. The chief engineering feature of the eleventh century was the building of numerous churches, castles, abbeys, and monasteries; also the first English stone bridge was begun at Bow. In the twelfth century a large number of castles, abbeys, and priories were built. Almost the only public work was some irrigation near St Albans. In the thirteenth century Bow Bridge was finished and a number of large cathedrals were built. In the fourteenth century there was a marked decline in England in the construction of new abbeys, monasteries, and priories, owing to the influence of Wickliffe. A town hall at Retford, Nottinghamshire, was built in 1388, some stone bridges, and Liverpool Old Haven (1332-56). In the fifteenth century little building was done in England and many old castles were destroyed during the Civil War. Some conduits were made and sewers and roads were improved. In the sixteenth century larger waterworks and conduits were made, besides dockyards; while lighthouses, harbours, and breakwaters were made or improved, and their development belongs to this century. Large churches and other buildings were erected. In the seventeenth century engineering continued on lines

similar to those of the previous century; the building of waterworks, lighthouses, dockyards, and docks being the chief feature. There were also drainage works and land reclamations. A few churches and many palaces and town halls were built, while new classes of miscellaneous buildings such as theatres, exchanges, banks, and custom-houses began to be created. In the eighteenth century the first iron bridges were constructed, also canals, and numerous and large bridges. Useful buildings became larger and more frequent and public works ceased to be rarities. In England the special feature of the century was the construction of the canals. The early nineteenth century was similar, but the construction of the canals greatly improved many industries. Better coach-roads followed, and then railways, and with the introduction of railways engineering progress received a great impetus. From that time onwards science and invention have grown at a rapidly increased rate, which seems likely to continue.

The table on page 39 showing the production of pig-iron at different dates illustrates the remarkable increase in engineering energy, for the output of pig-iron is an indicator of the amount of work done. From 17,350 tons produced in 1740, to 581,367 tons in 1825 is a marked increase, but in 1840 the output had jumped to 1,396,400 tons following the introduction of railways, and in 1900 had grown to 8,959,691 tons. An increasing population naturally required an increasing output of iron, but while the population had multiplied about five times between 1740 and 1900 the iron output had multiplied about five hundred and sixteen times, showing the enormous increase in engineering activities. It is to be remembered, however, that iron was being imported when the British output was small and so the rate of increase may not be quite so marked as appears.

The increase in the population was caused almost entirely by the growth of the towns. It has been estimated that the population working on the land when Domesday Book was compiled, was much the same as now. Domesday Book omitted Northumberland, Cumberland, Westmorland, Lancashire, and Monmouthshire, and estimated that in the rest of England there were 9 million acres ploughed and 1 million acres of meadow, besides much pasture. In 1916 there were 10 million acres of arable and 12 million acres of combined meadow and pasture land. A table given by Toynbee brings out the same fact. The twelve most populated counties in England and Wales at different dates were as follows; the figures give the number of persons per square mile.

1700		1750	
Middlesex	2,221	Middlesex	2,283
Surrey	207	Surrey	276
Gloucestershire	123	Warwickshire	159
Northamptonshire	121	Gloucestershire	157
Somerset	119	Lancashire	156
Worcestershire	119	Worcestershire	148
Hertfordshire	115	Hertfordshire	141
Wiltshire	113	Staffordshire	140
Buckinghamshire	110	Durham	138
Rutland	110	Somerset	137
Warwickshire	109	Yorks, W. Riding	135
Oxfordshire	107	Buckinghamshire	131

1881	
Middlesex	10,387
Surrey	1,919
Lancashire	1,813
Durham	891
Staffordshire	862
Warwickshire	825
Yorks, W. Riding	815
Kent	600
Cheshire	582
Worcestershire	515
Nottinghamshire	475
Gloucestershire	455

Omitting Middlesex and Surrey, which contain London, the growth in density of population is most marked in the case of Lancashire, which in 1700 was not one of the ten, but in 1881 was easily first of all; this, of course, being due to the growth of the industries. Northamptonshire, second in 1700, does not appear at all in the later lists. The purely agricultural counties, such as Buckinghamshire, Rutland, and Oxfordshire, have not altered much in population for many centuries; although even here small towns have added slightly to its density.

The population of England and Wales was divided, at the dates stated, as follows:

	Rural Districts	Percentage of population in Rural Districts	Urban Districts
1851	8,936,800	49.8	8,990,809
1881	8,683,026	33.3	17,285,026
1911	7,907,556	21.9	28,162,936

In 1377, according to A. P. Usher, England contained 9 towns with more than 5,000 inhabitants, including 3 with over 10,000 (London 37,302, York 11,597, Bristol 10,152); also 11 towns with 3,000 to 4,999; 19 with from 1,000 to 2,999; and 3 towns with less than 1,000. Compare these figures with the preliminary figures of the 1921 Census (*Times*, 24th August) which give 46 towns in England and Wales with more than 100,000 inhabitants and also 55 with more than 50,000!

The next table, from Toynbee, shows the population of 12 great provincial towns at various dates:

	1685	1760	1881(g)	1921(h)
Liverpool .	4,000(a)	40,000(c) 30-35,000(d) 34,000(e)	552,425	803,118
Manchester	6,000(a)	30,000(c) 40-45,000(d)	393,676	730,551
Birmingham	4,000(a)	28,000(b) 30,000(d)	400,757	919,438

	1685	1760	1881(g)	1921(h)
Leeds .	7,000(a)	—	309,126	458,320
Sheffield .	4,000(a)	30,000(c) 20,000(d)	284,410	490,724
Bristol .	29,000(a)	100,000(d)	206,503	377,061
Nottingham	8,000(a)	17,000(f)	111,631	262,658
Norwich .	28,000(a)	40,000(c) 60,000(d)	87,843	120,653
Hull . .	—	20,000(c) 24,000(d)	161,519	287,013
York . .	10,000(a)	—	59,596	—
Exeter .	10,000(a)	—	47,098	—
Worcester .	8,000(a)	11-12,000(c)	40,421	—

References.—a=Macaulay's History of England; b=Defoe's Tour; c=Arthur Young (1769); d=Macpherson's Annals of Commerce (1760); f=Eden's State of the Poor (1797); g=Census Returns for the Parliamentary District; h=do. as quoted in the *Times*, 24th August, 1921.

We may add that about 1819 Birkenhead contained 44 houses only (population 1921 is 145,592); in 1801 Middlesbrough had a population of 239 (population 1921 is 131,103). The growth of London is mentioned in Chapter V, p. 187.

The development of the towns has caused Man's geological activities to grow by leaps and bounds. Increased population and engineering activity react on one another as a mutual spur, for a greater density of population requires the exercise of engineering skill to provide the necessary water, transport, lighting, and sanitation; as well as factories in which the people may earn their bread. These increased facilities cause a further growth in the population, which means still further demands on the engineer. This is the reason why the growth of population and of industry were so slow for centuries, before certain key inventions caused an increasing acceleration in both, until the population began to be too great for the area of the country to support without outside assistance. Industrial depression and emigration then came into

play and the growth in the British population became comparatively small from these causes.

Increasing population means increased artificial denudation by attrition of the ground and by excavation for useful minerals; it also means an increased area covered by buildings and roads and therefore protected from natural denudation. The increasing number of domestic animals also had a geological aspect, although the effect was chiefly biological and therefore beyond our scope. The sheep in the United Kingdom are estimated (Mulhall) to have numbered 12 millions in 1688 and 28,940,000 in 1888. The average for 1891-1900 was 27,002,123 and for 1901-10 was 26,162,399. The cattle were about 2,850,000 in 1774 and 10,270,000 in 1888, while the average for 1891-1900 was 6,641,706, and for 1901-10 was 6,873,623. These and other domestic animals must have had an effect on denudation by the mere attrition of their hoofs.

Every activity of Man described in the preceding pages became accelerated with the growth of population, but the acceleration would apparently be reduced as the rate of increase in the population fell off, when the struggle for existence became more acute, and was relieved in part by emigration.

In addition to direct denudation Man causes indirect denudation by modifying climate. In Chapter IX we noticed that desert conditions have been brought about in many parts of the world by the destruction of forests, and that, as a result, disastrous floods have swept away soil and dug deep ravines on cultivated lands. The denudation so caused is an unknown quantity, but even in Britain it is noticeable, while if the whole earth is considered the rock removed by these floods doubtless adds considerably to the rate of human denudation. To some extent irrigation, which reclaims desert regions, has helped to prevent denudation, but has not balanced the destructive forces.

Another result of human activity is more doubtful, and at present is in the speculative stage. On p. 305 we have referred to the possibility of a considerable increase in the amount of carbon dioxide in the atmosphere as the result of the burning of fuel, and the probable effect on climate of such an increase, if it occurs. The effect is likely to be in some degree inimical to the higher animals, and therefore to favour lower forms of life in the " struggle for existence "; and also to raise the average temperature of the earth. A more distinctly geological result would be an increase in the rate of denudation, for not only would more limestone be dissolved in a given time, but the ordinary processes of decay by atmospheric chemical action would be accelerated.

Truly it would seem as if " Man strews the earth with ruin." But this conclusion is too flattering to human vanity. Man's most permanent memorial is a rubbish-heap, and even that is doomed to be obliterated.

Perhaps the most difficult, and at the same time the most interesting, problem that arises in connection with our subject is the relation between Man's psychology and his geological activities. His most profound interferences with Nature have their origin in his thoughts, and it is the changes in Man's ideas that are responsible for the intermittency of his activities.

One or two instances will illustrate what may result from a change in fashion. At one time buildings were roofed with a variety of substances: straw, tiles, or local flag-stones; but in course of time the value of slate was discovered, and this material almost entirely superseded the others. From a geological point of view this meant that instead of clay or flag-stone being quarried, enormous excavations were made in hard slate rocks. At present there is a prevalent idea that a tiled roof is more artistic than a slate one, with the geological result that clay is excavated instead of a corresponding quantity of slate. Again, the thoughts

of such men as Brindley, the constructor of canals; of Telford, the road-maker; of George Stevenson, the locomotive builder; have had marked geological results, as is shown in the preceding pages. We are in the habit of distinguishing human activities as "artificial" as distinct from "natural," or those of Nature; and it seems very extraordinary that natural processes can apparently be interfered with by something outside Nature, i.e., by Man's thoughts.

The difficulty diminishes, or disappears, if we realise that our distinction between "artificial" and "natural" is unreal. We must remember that all living things produce geological effects, and that there is a gradation between the apparently mechanical work of the lower organisms and the deliberate acts of Man. Primitive Man's action on Nature was similar in character and degree to that of many other animals. During the early Stone Age Man's geological work consisted in chipping a few flints; beating a few pathways through the wilderness; and leaving behind him a few small heaps of burnt stones, literally his pot-boilers. Still more primitive Man did not know how to make a fire, or to shape a flint-implement, and was in all things like the beasts. The elephant and the buffalo were more effective pathway-makers, and the white ant surpassed him as a builder. Where, then, shall we draw a boundary between the works of Man and that of other animals?

The white ant, in parts of Africa, performs the geological functions of the earthworm of this country, but shows more brain-power by building the complicated structures in which it lives. The beaver builds dams and reservoirs in an intelligent manner, and is more of an engineer than some living races of men. Is then the beaver's work natural or artificial? It is the result of directed intelligence as much as is the Nile Dam or the Vyrnwy Reservoir. Moreover, the beaver is not even one of the higher mammalia, but a

relative of the rat and the rabbit. Clearly the so-called artificial is but a form of natural action, and so we must consider all Man's geological work to be as essentially natural as the work of the sea or of the atmosphere, but differing in the relatively very brief period of activity. Because of the brevity of the period, Man's work will sink into insignificance when viewed as part of geological history. Nevertheless, during the present short chapter of that history Man's work is very important, and as worthy of a place in geological text-books as are the actions of the sea or the rivers.

If we compare Man's influence on the earth with that of other animals and plants it is probably no greater than that of some organic agents of the past. So far as we know, the lands, during the early geological ages, were either bare or covered only by such simple plants as algæ (plants such as the *Protococcus*, which forms the green patches on tree-trunks), although some of these may have attained to a considerable size. When the Coal-measures flora had been evolved the land was completely changed, for the dense jungles in which coal was formed extended over a great part of the Northern Hemisphere. The conditions of sedimentation and denudation must have been revolutionised by the growth of these plants, and, moreover, it is probable that the climate of the whole globe was fundamentally altered (see p. 302) by the removal of a vast mass of carbon from the atmosphere. The geological effect of plant life during the Coal-measures period was at least equal to that of Man, and no one would deny its purely " natural " character, or see in the growth of coal, and all it involves, any interference with Nature by Life.

In spite of variations in the mode of attack, it seems that the rate of human denudation, as a whole, has been increasing rapidly until the present time. An interesting question is, will the rate continue to increase, or even be maintained at its present level, in

the future? There are indications of diminution before long. The increasing price and scarcity of coal are likely to compel the utilisation of other kinds of power, and the first to be utilised will probably be water-power. The scheme for damming the Severn is a sign that the time has almost come for such projects, though not necessarily large schemes. Most of our rivers exhibit instances of power running to waste; one frequently sees, e.g., the surplus water of a reservoir, or of a navigation flowing over dams and weirs. Each weir at present represents waste energy, but the time will probably soon come when a small turbine will be attached to each small fall and electricity produced for local uses, such as lighting adjacent houses or pumping water from wells. When this change has been effected the rate of denudation will be greatly reduced, for we have seen that coal-mining is one of the chief forms of human denudation, and the water-power will take the place of coal to a greater or less extent. Secondly, the denudation due to rivers should be greatly diminished, for it is at falls that the rivers are most effective in erosion. Even a slow-flowing river like the Lea shows marked denudation below a weir, but if the water is utilised for power, denudation is done away with. In the case of a large waterfall, where the denudation is much greater, the diminution in the destructive power of the stream will be more marked. As denudation by streams is one of the most potent natural agents, the total amount of denudation will be considerably reduced. Increased protection of the sea-coast may also be expected, and so, on the whole, the prospect is that the present tendency of human interference to hasten denudation may shortly be replaced by an opposite tendency. This is in accordance with our idea of the impermanence of human geological activities.

This tendency to replace destructive by protective and renovative forces is shown by the marked increase

in irrigation works (p. 263). Can we foresee the final result when all possible engineering works shall have been carried out? Is it possible that in the yet far distant end Earth will come to the state said to exist in Mars, and be covered by enormous canals from pole to equator? The canals of Mars, if they really exist, a question still under discussion, are far greater than any our engineers have imagined. The battle of the Martians with Nature has been on a much more gigantic scale than Man's conflict, and yet we hear that the Martian is on the point of extinction, and Mars of becoming totally lifeless. Even on Mars the mighty engineering works seem merely to scratch the skin of the planet, and the final result of Martian activity on the solar system seems likely to be infinitesimal.

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P.I.C.E. for Proceedings of the Institute of Civil Engineers, London.
Q. for The Quarry and Builders' Merchant, London.
B.C. for The British Clayworker, London.
W. for Water and Water Engineering, London.
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